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20 December 1943

ANC BULLETIN

WOOD AIRCRAFT INSPECTION AND FABRICATION

WAR DEPARTMENT
ARMY AIR FORCES

NAVY DEPARTMENT
BUREAU OF AERONAUTICS

DEPARTMENT OF COMMERCE
CIVIL AERONAUTICS ADMINISTRATION

Issued by
ARMY-NAVY-CIVIL COMMITTEE
on
AIRCRAFT DESIGN CRITERIA

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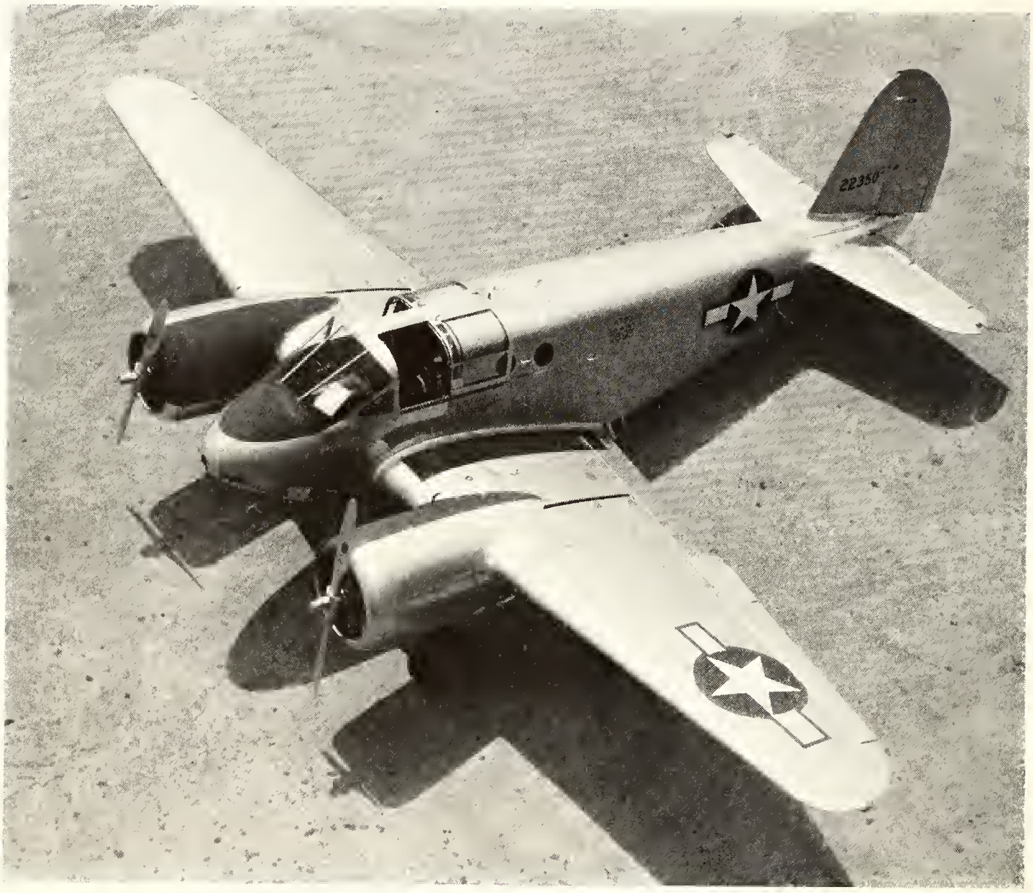

Training plane of modern plywood construction.

CHAPTER I. GENERAL

1.0. PURPOSE AND USE OF BULLETIN

1.00. Introduction. This bulletin has been prepared for use in the inspection and fabrication of both military and commercial aircraft, and contains material which is acceptable to the Army Air Forces, Navy Bureau of Aeronautics, and Civil Aeronautics Administration. It should, of course, be understood that methods and procedures other than those outlined herein are also acceptable, provided they give equivalent results or provided they are properly substantiated and approved. The applicability of the inspection and fabrication procedures contained in this bulletin as contract or certification requirements will in each case be defined by the procuring or certificating agency.

1.01. Scope. The technical material in this bulletin, which is based chiefly on results of investigations conducted during the past 33 years by the Forest Products Laboratory, is limited to information on wood, modified wood, glues, and processing that is of direct concern to inspectors and fabricators of wood aircraft. Strength data and other design criteria are beyond the scope of this bulletin. For such data the reader is referred to "Bulletin ANC-18, Design of Wood Aircraft Structures."

This bulletin supersedes the publications entitled "Manual for the Inspection of Aircraft Wood and Glue for the United States Navy" issued in 1941 by the Navy Department Bureau of Aeronautics and the "Wood Aircraft Fabrication Manual" issued in 1942 by the Aeronautical Board.

1.02. Acknowledgement. The many staff members of the Forest Products Laboratory participating in the preparation of this bulletin wish to express their appreciation to aircraft manufacturers and others for the valuable assistance given in connection with the various parts of this bulletin, the extent of which is too great to make practical separate acknowledgments.

CHAPTER 2. WOOD

2.0. BASIC INFORMATION ON WOOD AS AN AIRCRAFT MATERIAL.

2.00. General. Wood consists mainly of hollow fibers built up of interconnected cellulose chains arranged more or less spirally around the fibers in the direction of their longest dimension. The walls of the fibers and other cells are infiltrated with an amorphous material called lignin which also binds the cells together so firmly that, when wood is ruptured under stress, separation usually occurs within the fiber walls rather than in the bond between the fibers. Therefore, for mechanical purposes wood may be considered as being made up of tubes of indefinite length firmly welded together rather than separable fibers of varying lengths. Unlike metals, which have generally uniform strength in all directions and whose every cubic inch is identical, wood has not, for instance, the same strength across the grain as parallel to the grain; its tensile strength may vary as much as 40 to 1, its crushing strength 7 to 1, and its modulus of elasticity 150 to 1. Not only do different species of wood differ in their properties, but trees of the same species and even parts of the same tree may vary, depending on the growth conditions prevailing when the wood was formed.

Most substances expand more or less when heated. In the case of wood, the thermal expansion is so small as to be unimportant in ordinary usage.

Any piece of wood will give off or take on moisture from the surrounding atmosphere until the amount of moisture in the wood balances with that of the atmosphere. Wood, like many other hygroscopic materials, shrinks as it loses moisture and swells as it absorbs moisture. Wood shrinks most across the grain in the direction along the annual rings (tangentially), about ½ to ⅔ as much across these rings (radially), and very little, as a rule, along the grain (longitudinally). Although certain coatings when applied to wood will greatly reduce the rate at which it takes on or gives off moisture to the atmosphere, there is no practical coating that will prevent wood from changing its moisture content over a long period of time.

It is not always possible to proportion a solid plank so as to develop the necessary strength in every direction and at the same time utilize the full strength of the wood in all directions of the grain. It is the purpose of plywood, which is made up by gluing several plies or sheets of veneer together, to meet this deficiency by so combining the various plies that the grain of any one ply is usually at right angles to the grain of the adjacent ply or plies, which results in a redistribution of the material.

The properties of wood can also be modified by resin treatments, and a combination of resin treatment and compression. Promising new materials with marked stability against swelling and shrinking are thus made up of veneer impregnated with resins and pressed into solid pieces.

By laminating and molding thin layers of wood or veneer to shape during the gluing operation, structures of sharp single curvature and complex double curvature are readily and efficiently produced.

2.01. Heartwood and Sapwood. In most woods three regions are readily discernible in the end surface of the log: (1) the bark; (2) a light-colored layer next to the bark, called the sapwood; and (3) an inner body, usually darker than the sapwood, called the heartwood (fig. 2–1). In the structural center of the tree trunk there is a small, soft core—the pith.

FIGURE 2-1.—Cross section of white ash log, showing irregularly shaped heartwood at center, wide sapwood, annual rings in both sapwood and heartwood, and bark.

In the sapwood many of the cells (parenchyma) are alive and serve mainly in the transfer and storage of food, which accounts in part for its greater susceptibility to attack by certain fungi and insects. Most of the cells, however, are dead and serve only as channels for the movement of sap and to add strength to the tree trunk. In the heartwood all of the cells are dead and function mainly in supplying strength to the trunk.

In some woods there is little or no difference in color between heartwood and sapwood. Spruce (except Sitka spruce), hemlock, the true firs, Port Orford white-cedar, basswood, cottonwood, and beech are examples of this class, whereas in pine, Douglas-fir, baldcypress, ash, oak, maple, birch, sweetgum, and numerous other species there is a well-marked contrast between sapwood and heartwood. In Sitka spruce the sapwood normally is white and the heartwood pale reddish brown.

Although the sapwood is, as a rule, light in color, it may be discolored by sap stain, wood-destroying and other fungi, chemical stains within the wood, and color leached from the bark. The color of the heartwood may be of a uniform shade or it may be streaked or variegated, as is often the case in sweetgum. The outer part of the heartwood of old Douglas-fir trees often is yellowish in color in contrast to the more reddish inner part of the trunk. Heartwood infected with decay may be discolored in various ways (sec. 2.3213).

Light-colored zones, known as internal sapwood, are occasionally found in the heartwood of Douglas-fir, Sitka spruce, western redcedar, western larch, and other species.

The thickness of the sapwood layer varies considerably as between different species. In black ash, black cherry, northern white-cedar, western redcedar, Douglas-fir, and spruce it is usually less than 1½ inches and consequently constitutes but a relatively small part of the lumber cut from these species. In white ash, birch, maple, and hickory, on the other hand, the sapwood is so thick that it often comprises more than half the cut.

Within each species the sapwood is thickest in the most vigorous trees, especially those grown in the open. The sapwood decreases in thickness from the stump to the top of a tree trunk as a rule, but nevertheless the proportion of sapwood to heartwood generally increases toward the top.

Year by year, as a tree increases in diameter by the addition of new layers of sapwood under the bark, the zone of heartwood enlarges at substantially the same rate. The change consists principally in the death of the adjacent sapwood and its transformation into heartwood by the infiltration of coloring matter and various other materials into its cell walls and cell cavities. In woods which have tyloses (p. 9) the pores become partially or completely plugged with these ingrowths as the sapwood turns into heartwood, or in some species many years before. The circumference of the heartwood often is irregular and does not necessarily follow the annual rings (fig. 2–1).

Heartwood is not fundamentally weaker or stronger than sapwood, but there are some changes in physical characteristics, besides change in color, which accompany heartwood formation. After the timber is cut, the heartwood usually is more resistant to the attack of certain insects and to decay, stain, and mold than the sapwood. In the living tree the sapwood is usually less subject to attack, whereas specific fungi often infect the heartwood (p. 113). Heartwood is less permeable to liquids, as a rule, which is an advantage in many uses but a disadvantage in the injection of preservatives. Because it is less permeable, heartwood seasons at a slower rate than the sapwood. In resinous species the heartwood usually contains more resin than the sapwood.

2.02. Cellular Structure. Wood is composed of cells tightly grown together for the most part. The cells vary considerably in size and shape within a piece of wood and as between species. The principal kinds of cells and their usefulness in identifying wood species are discussed on pages 9 to 11. On account of the cellular structure of wood, its mass is distributed over a large cross section, thereby giving it relatively high bending strength and stiffness per unit of weight, but relatively low hardness per unit of area.

The specific gravity of all wood substance is practically the same; therefore, the great differences in specific gravity and, consequently, in strength and hardness of different species of wood are due largely to differences in size of cell cavities and thickness of their walls.

2.03. Annual Rings. In timber grown in temperate climates well-defined concentric layers of wood can be seen on the cross section.

These layers correspond closely to yearly increments of growth and for that reason are called annual rings (fig. 2–1). Many tropical timbers show no well-defined annual rings, because growth in them is more or less continuous throughout the year.

The annual rings in trees vary in width with the environmental conditions (stand density, soil moisture, etc.) under which the trees grew. In trees that started growth in the open the annual rings are wide at the center and narrower toward the bark, as a rule, but in trees that came up in a forest the rings are likely to be narrow at the center and wider farther out. In some logs the rings average wider at the top and in others at the butt end. In leaning softwood trees the annual rings usually are wider on the lower side, and in leaning hardwood trees on the upper side.

2.04. Springwood and Summerwood. Springwood is the wood formed on the inner side of the annual ring during the early part of each growing season. It is usually more porous, softer, weaker, and, especially in the conifers, lighter in color than the summerwood, which is formed in the outer part of the annual ring during the latter part of the growing season. Segments of annual rings in a cross section of Douglas-fir, magnified 15 diameters, are shown on page 38. The dark layer in the upper part of each segment is the summerwood, and the lighter layer in the lower part is the springwood. The two may be fairly sharply differentiated from each other within each annual ring, as in Douglas-fir and oak, or the transition may be gradual, as in walnut. In some woods (for example, yellowpoplar, birch, maple, basswood, cottonwood, and sweetgum) the transition from springwood to summerwood within the annual ring is not clear. The division between rings is, however, plain enough.

The width of the summerwood and the percentage that it occupies in the total width of the annual rings varies considerably in some species, as yellow pines, Douglas-fir, oaks, ashes, and hickories, according to the vigor of the tree at the time the rings were formed.

2.05. Plain-sawed and Quarter-sawed Lumber. Wood can be cut in three distinct planes with respect to the annual layers of growth: crosswise, exposing the transverse or end-grain surface; lengthwise along any of the radii of the annual rings, exposing the radial or so-called quarter-sawed, edge-grain, or vertical-grain surface; and lengthwise tangent to any of the annual rings, exposing the tangential or so-called plain-sawed or flat-grain surface. Quarter-sawed and plain-sawed boards are shown in figure 2–2.

Quarter-sawed lumber shrinks and swells less in width and twists, cups, slivers, surface checks, and casehardens in seasoning less than plain-sawed lumber. On the other hand, plain-sawed lumber is cheaper to produce and does not "collapse" so easily in drying in species subject to this particular defect, such as western redcedar, redwood, sweetgum, and swamp oak; also, any knots that are present are round or oval instead of long spike knots.

The annual rings often run diagonally across the end of a board so that it cannot be said to be either strictly plain sawed or quarter sawed. Squared dimension stock may show two plain-sawed and two quarter-sawed faces, or all four of an intermediate form.

2.06. Grain and Texture. The terms "grain" and "texture" are used rather loosely in connection with lumber. "Grain" is used in referring (a) to the annual rings, as coarse, fine, even, edge, and flat grain; (b) to the direction in which the fibers run, as straight, spiral, interlocked, wavy, and curly grain; and (c) to the relative size of the pores and the fibers, as open grain and close grain.

"Texture" is often used synonymously with grain. In addition it is used to express certain physical aspects of wood quality, as "hard texture" and "soft texture," "tough texture" and "brittle texture," but the word "texture" adds nothing specific to the meaning of such terms and may as well be omitted.

"Texture" is sometimes described as "good" or "poor" depending on the appearance of wood, its reaction under the pick test (lifting a splinter by means of a pointed instrument and observing how it breaks), or splitting off a sliver and break-

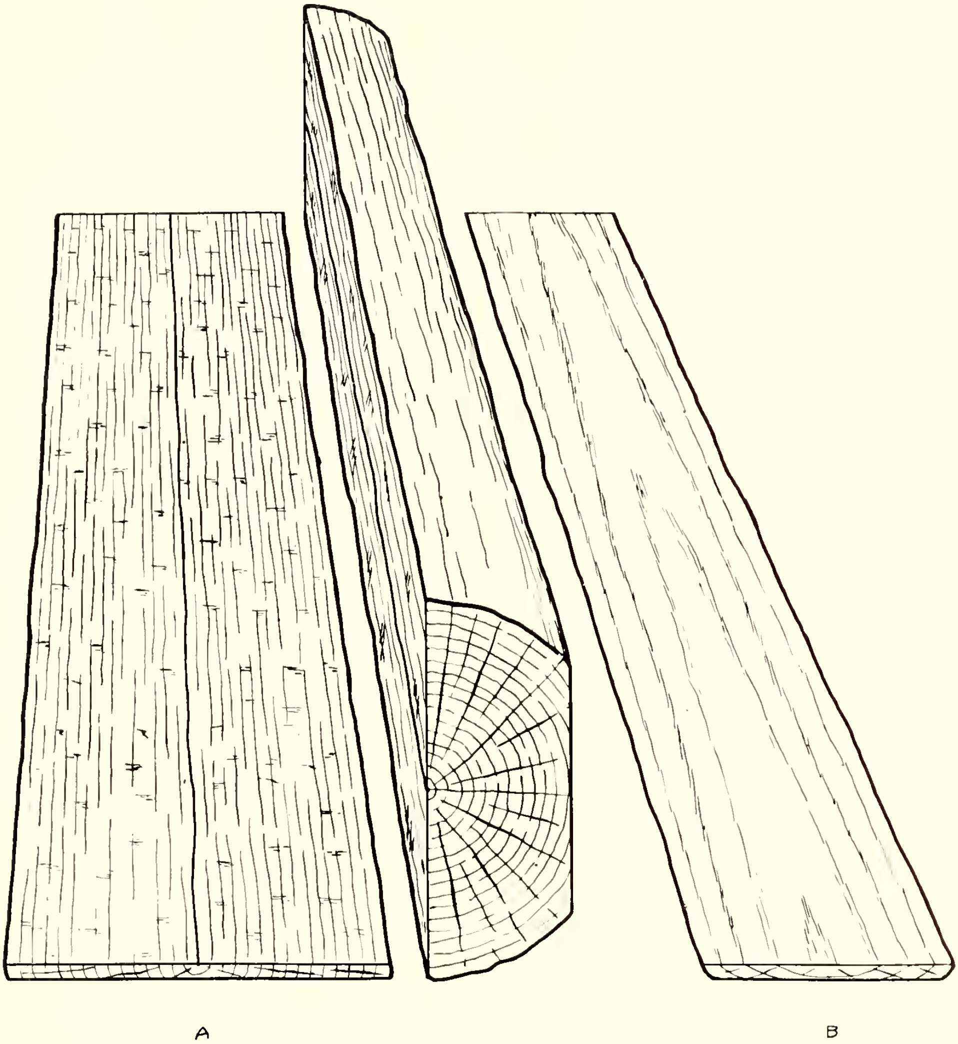

FIGURE 2-2.—Quarter-sawed (*A*) and plain-sawed (*B*) boards cut from log.

ing it in the hand, but such tests are not so reliable or definite as specific gravity, rings per inch, and slope of grain for designating wood quality.

For the sake of clearness, it is recommended that the annual rings be referred to as such, except with respect to the terms "edge grain," or "vertical grain," and "flat grain," which are thoroughly established and fixed in their meaning, and that (except as just stated) the use of the term "grain" be confined to the direction of the fibers; for example, straight, spiral, wavy, and interlocked grain. The term "texture" should be used to express the relative size of the pores and fibers or the relative amounts of springwood and summerwood, as coarse and fine texture, even and uneven texture.

2.1. IDENTIFICATION OF WOOD.

2.10. Meaning of the Terms "Hardwoods" and "Softwoods." Those who work with or handle wood usually identify the different kinds by their general appearances.

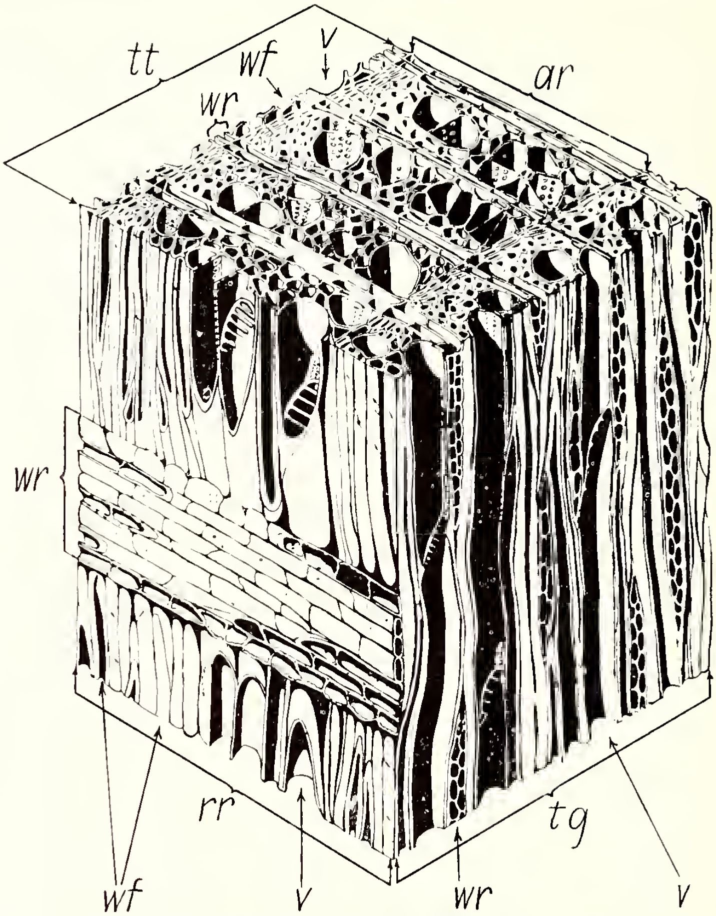

FIGURE 2–3.—Drawing of a small cube of hardwood highly magnified: *tt*, tranverse surface; *rr*, radial surface; *tg*, tangential surface; *ar*, annual ring; *wr*, wood ray; *wf*, wood fibers; *v*, vessels, or pores.

In describing to others how to identify wood, however, specific differences must be pointed out, since general appearances cannot be described with sufficient accuracy to differentiate any considerable number of woods. The specific differences most useful in wood identification are found in the cellular structure, color, odor, taste, weight, hardness, and, in some cases, exudation of resin or oil.

All woods can be grouped in two general classes: The hardwoods, which come from trees with broad leaves, and the softwoods, or conifers, which come from trees with needlelike or scalelike leaves. The terms "hardwoods" and "softwoods" are not descriptively exact, since some of the so-called softwoods, as southern yellow pine and Douglas-fir, are harder than some of the so-called hardwoods, as basswood and cottonwood; but the terms have been in use so long that their meaning has become definitely established. The structure of these two classes of wood is fundamentally different. Within each class there are considerable variations in structure, which aid in further identification as to genera and species.

2.11. Structure of Hardwoods. The hardwoods differ from the softwoods as a class in the presence of larger cells, constituting pores, or vessels, scattered among the smaller ones, which are mostly fibers. Figure 2–3 shows the pores and other cells in a hardwood cube highly magnified. The pores serve primarily in conducting sap from the roots to the leaves. In many hardwoods the pores can be seen distinctly without magnification as small holes on smoothly cut cross sections and as fine grooves on planed longitudinal surfaces. In other hardwoods the pores are so small that they cannot be seen without magnification.

In some hardwoods the pores formed at the beginning of each year's growth are decidedly larger than those formed later in the growing season. Such woods are called ring porous. Oak, ash, and hickory are examples (pp. 14, 16, and 20). In other hardwoods the pores are more or less uniform in size in each year's growth. Such woods are called diffuse porous. Maple, birch, and sweetgum are examples (pp. 26, 28, and 29). A certain arrangement of the pores within each annual ring also is characteristic of each species of wood and helps in its identification.

In certain hardwoods the pores in the heartwood and inner sapwood become more or less plugged up with ingrowths from the neighboring cells, known as tyloses, which usually have a glistening or iridescent appearance (p. 14). In other woods the pores are partly filled with dark-colored gum, while in still others they are empty. These variations in pore contents are a fairly reliable aid in wood identification.

The fibers in hardwoods are so small that they cannot readily be distinguished individually with a hand lens. Their function is to give strength to the wood. They average about one twenty-fifth inch in length, but their length has no relation to their strength, since when wood fails in tension or compression the fibers do not slip by each other, as in a rope, but break or buckle within themselves. The thickness of the fiber walls, however, greatly affects their strength.

Scattered among the pores and fibers of many wood species are parenchyma cells, which serve to store excess food. When aggregated into groups, they form light-colored tissue which may appear on the cross section as a "halo" around the pores, as in the summerwood of ash; or as numerous fine tangential lines, as in oak and hickory; or as boundaries to the annual rings, as in yellowpoplar and magnolia. Various modifications of the types of cells so far described also occur in wood, but they are of no value in identification except when a compound microscope is used.

In addition to the vertically arranged cells described, there are strips of horizontally elongated cells in wood which extend radially from the bark inward, and are known as rays, or wood rays (formerly called "medullary rays") (fig. 2–3). Their function is to conduct sap radially and to store excess food. In oak the rays are distinctly visible as broad lines on the cross section and as large "flakes" from a fraction of an inch to several inches high on radial surfaces. In all other native commercial species they are much smaller, often not being visible on a cross section without a lens.

2.12. The Structure of Softwoods. In softwoods the bulk of the wood is composed of fibrous cells, tracheids, averaging about one-fourth inch in length, which serve the combined purpose of the pores and wood fibers of hardwoods. They are almost uniform in width tangentially, and are arranged in definite radial rows. Figure 2–4 shows a drawing of a small softwood cube highly magnified. On account of the absence of pores, the softwoods are also called nonporous woods, although "porous" in the sense of containing empty spaces or absorbing liquids applies to both softwoods and hardwoods. On a smoothly cut cross section the fibrous cells can be seen with a hand lens, resembling in their regularity the cells of a honeycomb, except that in the outer part of each annual ring they are flattened radially and thicker walled, producing a denser band of summerwood (pp. 34, 38, and 43).

Rays are also present in softwoods, but they are always very small and on the cross section are invisible without a lens (fig. 2–4).

Resin ducts are passages extending vertically between fibrous cells and radially within certain rays. They serve for the storage and conduction of resin and are present normally only in the pines, spruces, larches or tamaracks, and Douglas-fir (pp. 32, 37, and 39).

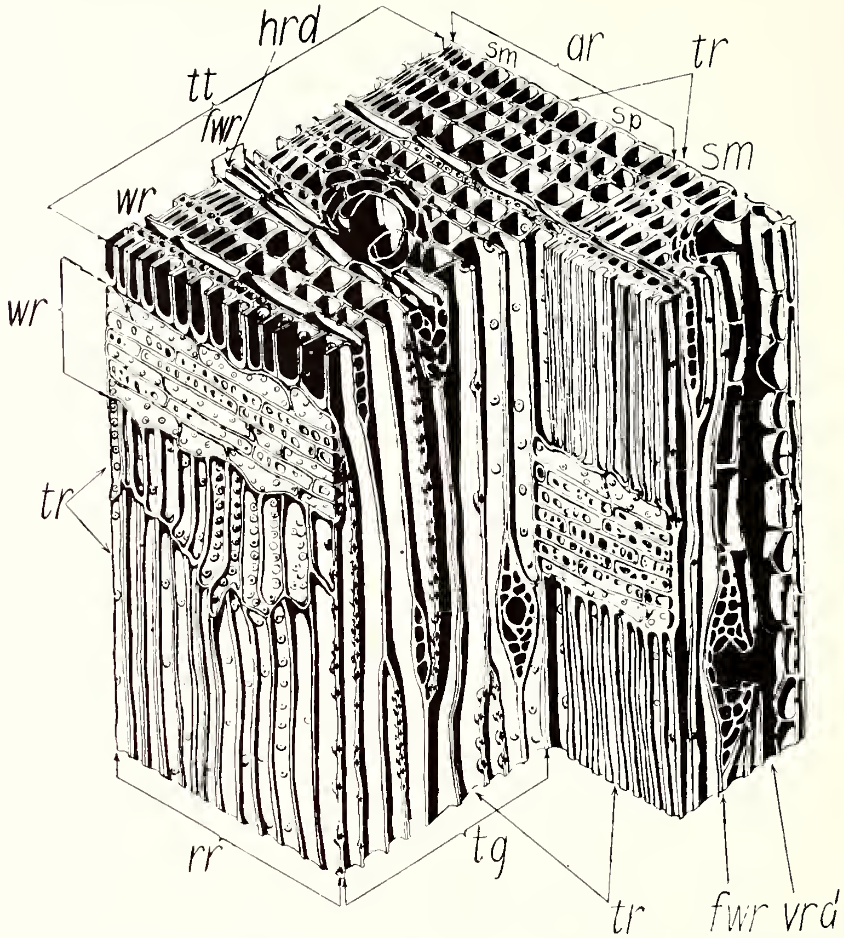

FIGURE 2-4.—Drawing of a small cube of softwood highly magnified; *tt*, transverse surface; *rr*, radial surface; *tg*, tangential surface; *ar*, annual ring; *sp*, springwood; *sm*, summerwood; *tr*, tracheid, or fiber; *wr*, wood ray; *fwr*, fusiform wood ray containing horizontal resin duct; *hrd*, horizontal resin duct. The large hole near the center of the transverse surface and the passage along the right edge are vertical resin ducts, *vrd*.

In the pines, the resin ducts are plainly visible with a lens and occasionally, on a smoothly cut cross section, barely visible without a lens. On longitudinal surfaces they are often visible as characteristic brownish lines. In the spruces, larches, and Douglas-fir they are smaller, less numerous, and, in the cross section, appear often in short tangential rows as whitish specks in the summerwood. On longitudinal surfaces of spruce and Douglas-fir, the resin ducts are less distinct than they are in the pines, but can usually be found on careful examination, especially by tilting the planed wood back and forth in the light. Since the resin ducts extend in the same direction as the fibers, the direction of the grain can be determined by them.

Exudations of resin and pitch pockets are common in woods containing resin ducts, and are not found in the cedars, baldcypress, redwood, hemlock, and true firs, which normally have no resin ducts. Oily exudations have been noted on the ends of Port Orford white-cedar stored in a warm place. The absence of exudations of resin, however, does not mean the absence of resin ducts. Resin will not exude, as a rule, on cuts made after the wood is seasoned; but warming pieces of pine, Douglas-fir, larch, and spruce in an oven or otherwise will usually cause enough resin to exude from the ends to form specks, thereby indicating the presence of resin ducts. This is especially true of pine and Douglas-fir, and to a less extent, of spruce and larch.

2.13. Physical Properties Useful in Identification. (a) Color: The color of wood is one of its most easily observed characteristics, and in some cases is sufficient for its identification. Frequently, however, the color is not sufficiently distinctive so that it can be described accurately. Furthermore, the color varies more or less for each species and is affected by light, moisture, decay, and other natural agencies which discolor the wood, so that it must be supplemented by other characteristics in identifying wood. A comparison of the color of a wood to be identified with known samples usually is of more value than any other impression that can be conveyed in writing.

In considering the color of wood, it should be remembered that heartwood and sapwood usually differ in color and that wood changes in color on long exposure to light and air. References to the color in the descriptions and key which follow are based on freshly cut longitudinal surfaces of sound heartwood, unless otherwise stated.

(b) Odor and taste: Some woods have a characteristic odor which helps in their identification after one is familiar with it or on comparison with known samples. Unfortunately odor cannot be described with any degree of accuracy. The taste of wood often resembles the odor, although exceptions occur. Both odor and taste are more pronounced in the heartwood than in the sapwood.

(c) Weight: When wood is dry, its weight aids in identification, although some species are highly variable in weight. For instance, the heavier grades of mahogany may weigh twice as much as the lighter grades.

Since no definite weight can properly be assigned to each species, descriptive terms based on specific gravity (weight when oven-dry and volume when green) class limits are used in connection with the descriptions of the woods that follow:

Specific gravity class	*Descriptive term*
Below 0.20	Extremely light.
From 0.20 to 0.25	Exceedingly light.
From 0.25 to 0.30	Very light.
From 0.30 to 0.36	Light.
From 0.36 to 0.42	Moderately light.
From 0.42 to 0.50	Moderately heavy.
From 0.50 to 0.60	Heavy.
From 0.60 to 0.72	Very heavy.
From 0.72 to 0.86	Exceedingly heavy.
Above 0.86	Extremely heavy.

(d) Hardness: The hardness of wood, as determined by its resistance to indentation or cutting (especially across the grain) is useful in distinguishing species with considerable differences in hardness, but this property is too variable and too difficult to determine with any degree of accuracy to be useful in distinguishing species of nearly the same average hardness. The hardness of each species of wood, like many other properties, is affected by density and moisture content.

2.14. Procedure in Identifying Wood. If the color, odor, or general appearance is not sufficiently distinct to identify a sample of wood, the more detailed structure must be taken into consideration. The structure and other physical properties of the various species that the inspector is likely to meet are described in the following pages, and a key has been prepared that will aid in their identification. The illustrations of the woods are photographs of thin cross sections magnified 15 diameters. They will prove helpful in studying the structure of each species or group of species.

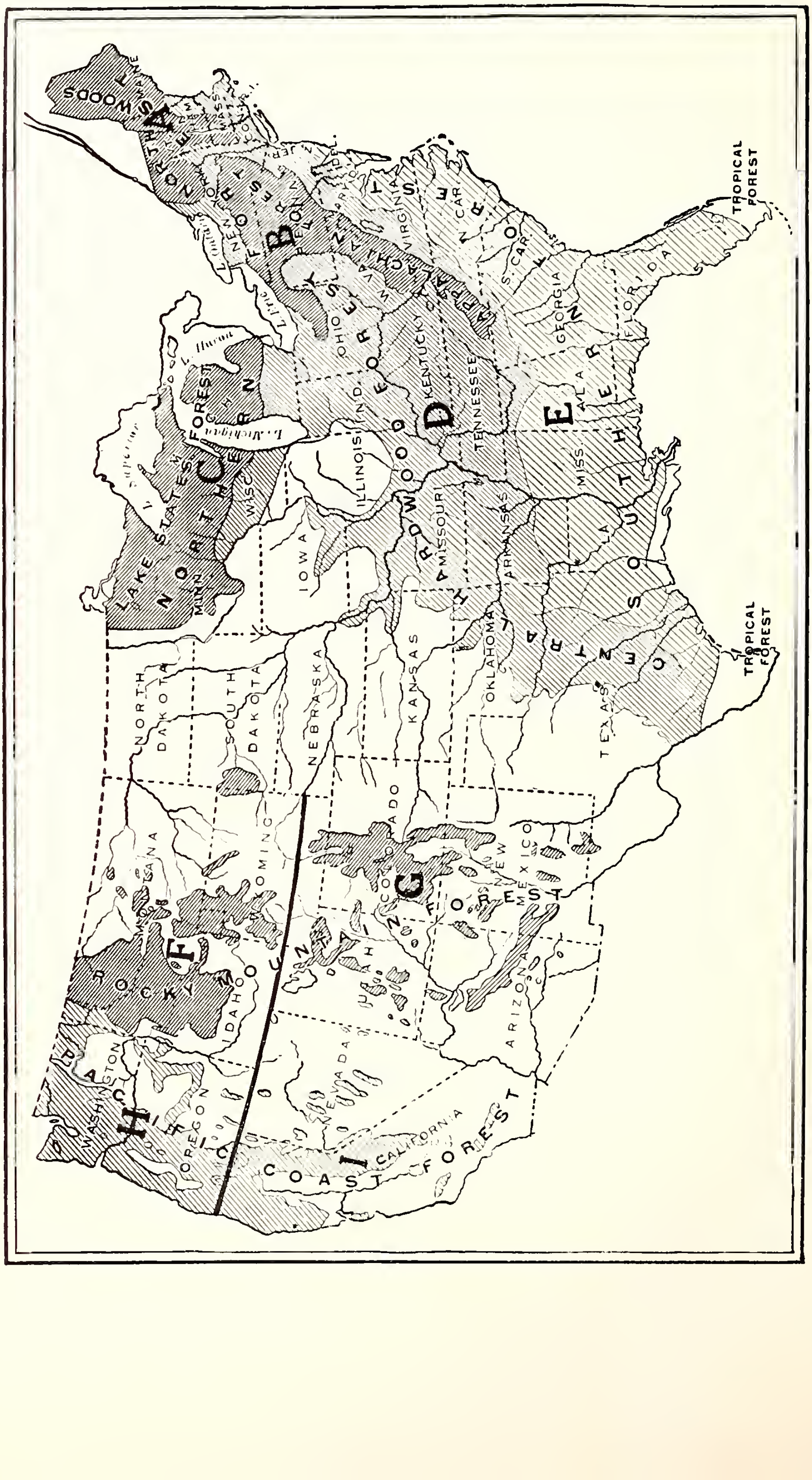

FIGURE 2-5.—Map of the United States showing forest regions referred to in text and indicated in text and on map by letters A to I.

The characteristic structure is usually seen to best advantage on a smoothly and freshly cut end surface across rings of average width. The area examined need not be large, but it is advisable to make observations at several places. Note first if pores are present. If pores cannot be seen with the unaided eye, use a hand lens. A lens magnifying from 8 to 15 diameters is preferable for this work. The lens should be held close to the eye and then the object brought within focus, care being taken not to shut out the light too much. If pores are present, note whether the wood is ring porous or diffuse porous, etc., as outlined in the key, pages 44 to 48. If pores are not present, try to classify the wood according to the subdivisions under the softwoods.

It is not expected that the key can be used successfully without some practice. The inspector should provide himself with known samples and study the illustrations of cross sections in the manual so as to become familiar with the terms used. Samples for comparison should be of heartwood of the tree trunk, showing average width of rings, and at least 3 inches from the center, or pith, of the tree.

2.15. Description of Woods in Key. The common and scientific names are those used by the Forest Service.

The letters after the names refer to the forest region in which the trees grow, as indicated on the map (fig. 2–5) although the geographic distribution of each species is not confined exactly to the limits of the regions indicated.

HARDWOODS

(a) THE WHITE OAK GROUP.

The following are the principal commercial species of the white oak group:

White oak (*Quercus alba*) (A, B, D, E).
Bur oak (*Quercus macrocarpa*) (A, B, C, D).
Swamp white oak (*Quercus bicolor—formerly Quercus platanoides*) (A, B, D).
Post oak (*Quercus stellata*—formerly *Quercus minor*) (E and southern half of B and D).
Chinquapin oak (*Quercus mühlenbergii*—formerly *Quercus acuminata*) (B, D, and all but eastern part of E).
Swamp chestnut oak (*Quercus prinus*—formerly *Quercus michauxii*), also known as cow oak (E).
Overcup oak (*Quercus lyrata*) (E).
Chestnut oak (*Quercus montana*—formerly *Quercus prinus*) (B and eastern half of D).

The woods of most of the species of the white oak group are so much alike in color and structure that no reliable means of identifying each species has been found. Chestnut oak can usually be distinguished from other species of the white oak group by the more open pores of the springwood in the heartwood.

The woods of the white oak group are heavy and hard on the average. The sapwood is mostly from 1 to 2 inches wide. The heartwood is grayish brown, usually without any reddish tinge. The dry wood is without characteristic odor or taste, but the green wood has a sour odor.

The annual rings are made very distinct by the large pores in the springwood, which form a porous ring from 1 to 3 pores wide. In the heartwood these pores are nearly all filled with tyloses, except in chestnut oak, in which they are more open but not so much so as in woods of the red oak group.

The pores of the summerwood are arranged in irregular, branched, V-shaped groups extending across the rings. They are very small and so numerous that they are difficult to count even under a good hand lens. This feature is an absolutely reliable means of distinguishing the commercial woods of the white oak group from

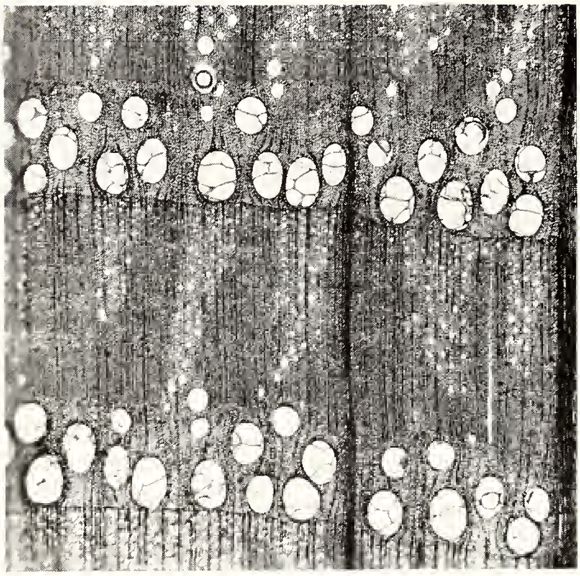

Figure 2-6.—Post oak. Cross section magnified 15 diameters.

Figure 2-7.—Chestnut oak. Cross section magnified 15 diameters.

those of the red oak group, the summerwood pores in the latter being larger and not so numerous. Compare illustrations of post oak (fig. 2–6) and chestnut oak (fig. 2–7), with illustrations of northern red oak (fig. 2–8) and pin oak (fig. 2–9), and also samples of the two groups.

The most characteristic feature of all oak woods, including the red oak and live oak groups, is the presence of certain broad rays, very conspicuous on the end surface and appearing on the radial surface as silvery "patches" from one-half inch to 4 inches in height with the grain.

Plain-sawed chestnut resembles plain-sawed white oak, but is lighter in weight and has only very fine rays.

(b) THE RED OAK GROUP.

The following are the principal commercial species of the red oak group:

Northern red oak (*Quercus borealis*) (A, C).

Eastern red oak (*Quercus borealis maxima*) (B, D).

Black oak (*Quercus velutina*), also known as yellow oak (B, D, E, and southern part of A).

Southern red oak (*Quercus rubra*—formerly *Quercus digitata*), also known as Spanish oak (E and southern part of D).

Swamp red oak (*Quercus rubra pagodaeofolia*—formerly *Quercus pagodaefolia*), also known as swamp Spanish oak (E).

Scarlet oak (*Quercus coccinea*) (B and D, except Texas).

Pin oak (*Quercus palustris*) (B, D).

Water oak (*Quercus nigra*) (E).

Willow oak (*Quercus phellos*) (E).

Laurel oak (*Quercus laurifolia*) (Southeastern part of E).

Blackjack oak (*Quercus marilandica*) (B, except northern part, D, E).

The wood of the species of the red oak group averages about as heavy and hard as that of the white oak group. The sapwood is from 1 inch to 3 inches wide. The heartwood usually has a reddish tinge, although occasional pieces resemble white oak in color. The dry wood is without characteristic odor or taste, but unseasoned wood has a sour odor.

The annual rings average wider than those in the woods of the white oak group and as a rule are more distinct because the springwood consists of mostly open pores forming a porous ring from 2 to 4 (1 in narrow rings) pores wide. Blackjack oak is an exception in that the springwood pores are mostly closed with tyloses, as in the woods of the white oak group.

The pores in the summerwood are larger but less numerous than those in the white oak group, and can easily be counted under a hand lens. (Compare figs. 2–6 and 2–8.) An inspector should provide himself with a half-inch cube of heartwood of the white oak group and one of the red oak group, both showing rings of average width and cut smoothly across the ends. These cubes may be tied together, thus affording a convenient means of comparison.

(c) THE ELMS.

American elm (*Ulmus americana*), also known as white elm, soft elm, and gray elm (A, B, C, D, E).

Slippery elm (*Ulmus fulva*—formerly *Ulmus pubescens*), also known as red elm (A, B, C, D, E).

Rock elm (*Ulmus thomasii*—formerly *Ulmus racemosa*), also known as cork elm (A, B, D).

Cedar elm (*Ulmus crassifolia*) (Western part of E).

The wood of the American and slippery elms usually is moderately heavy and easy to work; that of the rock elm and cedar elm is heavier, harder, and ranks

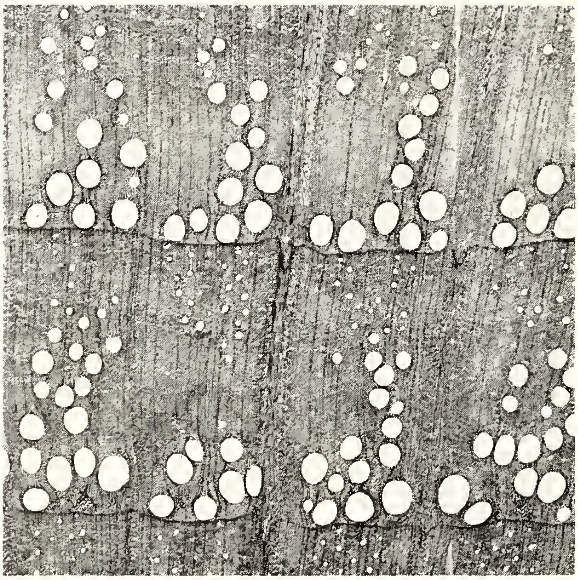

FIGURE 2-8.—Northern red oak. Cross section magnified 15 diameters.

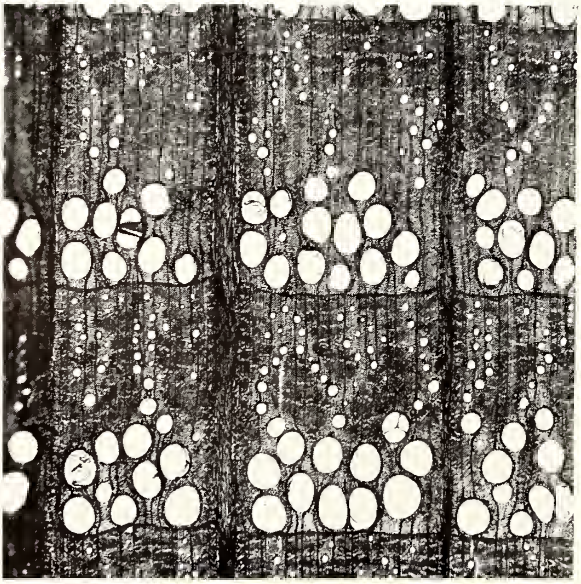

FIGURE 2-9.—Pin oak. Cross section magnified 15 diameters.

higher in mechanical properties, as a rule. All species vary, however, as is shown in the following tabulation of specific gravities of the species for which data are available (table 2–1):

Table 2–1.—*Specific gravity values of three elms.*

Species	Specific gravity based on weight when oven dry and volume—					
	When green			When oven dry		
	Minimum	Average	Maximum	Minimum	Average	Maximum
Rock elm	0. 43	0. 57	0. 73	0. 50	0. 66	0. 93
Slippery elm	. 39	. 48	. 63	. 44	. 57	. 75
American elm	. 38	. 46	. 57	. 43	. 55	. 68
Cedar elm	. 49	. 60	. 67	. 55	. 71	. 81

The sapwood varies from about one-half inch wide in slippery elm to 2 or 3 inches wide in white elm, with rock elm and cedar elm intermediate. The heartwood is brownish, usually with a reddish tinge, being darker in slippery elm than in the other species. The wood is considered practically tasteless and odorless, but slippery elm has a slight odor resembling that of the bark, which is familiar to many on account of its medicinal uses. The elms usually have interlocked grain, which gives them a tendency to warp.

The annual rings are most conspicuously defined in slippery elm and least in rock elm and cedar elm. In slippery elm, the springwood consists of several rows of large pores as a rule, but in white elm, rock elm, and cedar elm only one row of large pores is present, except in very wide annual rings. In rock elm and cedar elm, the springwood pores are smaller than in American elm and are usually filled with tyloses in the heartwood, so as to make them inconspicuous on a cross section. (Compare figs. 2–10 and 2–11.) This difference in the size and number of the pores of the springwood is probably the most reliable means of distinguishing the species of elm. The pores of the summerwood of all the elms are very numerous and joined in more or less continuous wavy tangential lines found in no other commercial wood except hackberry. Hackberry, however, has light gray heartwood tinged with green; and the rays are distinct without a lens, while in the elms they are not visible to the unaided eye.

(d) The Ashes.

White ash (*Fraxinus americana*) (A, B, C, D, E).
Green ash (*Fraxinus pennsylvanica lanceolata*) (A, B, C, D, E).
Black ash (*Fraxinus nigra*), also known as brown ash and hoop ash (A, C, and northern parts of B and D).

The above three species comprise about 98 percent of all the ash cut. The white ash and green ash are very much alike and are sold as "white ash" or "ash."

The sapwood of the white and green ashes is comparatively wide and white. The heartwood is grayish brown, occasionally with a reddish tinge. In the black ash the sapwood is narrow, usually less than 1 inch wide, and the heartwood is grayish brown, without any reddish tinge. Black ash averages considerably lighter in weight than the other two species, but the wood in the swelled butts of white ash growing in very wet swamps of the South often is lighter than that of black ash.

Ash wood, especially black ash, has a faint odor when worked but for all practical purposes is considered odorless and tasteless.

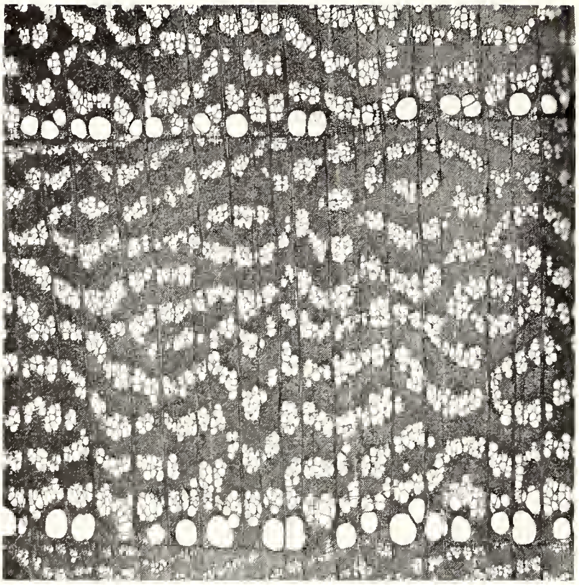

FIGURE 2-10.—American elm. Cross section magnified 15 diameters.

FIGURE 2-11.—Rock elm. Cross section magnified 15 diameters.

All three species have definite annual rings made very conspicuous by several rows of large pores in the springwood. In the summerwood the pores are few, very small, and isolated, or occasionally two or three in a radial row (fig. 2–12). In the white and green ashes the summerwood pores are surrounded by light-colored tissue (parenchyma) which projects tangentially, producing light-colored lines often joining pores somewhat separated, especially in the outer portion of the annual ring. (This is not shown as clearly in the illustration of white ash, figure 2–12, as it appears on a smoothly cut end surface by reflected light.) In black ash wood the parenchyma is scant and projects little, if any, from the pores.

The rays in all the ashes are too fine to be distinctly visible without a lens.

Chestnut resembles the heartwood of the ashes, especially black ash, but is lighter in weight and has comparatively many pores in the summerwood, the pores being arranged in radial groups. Elm can be distinguished from ash by its numerous summerwood pores arranged in wavy tangential lines.

(e) THE TRUE HICKORIES.

Shagbark hickory (*Carya ovata*) (A, B, D, and northern part of E).
Shellbark hickory (*Carya laciniosa*) (D).
Mockernut hickory (*Carya tomentosa*) (B, D, E).
Pignut hickory (*Carya glabra*), also known as black hickory (B, D).

The wood of the true hickories is very heavy and very hard and ranks high in toughness as a rule.

The sapwood is several inches wide. The heartwood is reddish brown and is without characteristic odor or taste.

The annual rings are clearly defined by a zone of larger pores in the springwood. The pores in both springwood and summerwood are rather few and isolated. The most characteristic feature of the hickories is the numerous (5 to 20) fine, light-colored tangential lines (parenchyma) in each annual ring. A lens is necessary to see these lines distinctly. The rays are not visible without a lens (fig. 2–13).

Hickory is not easily confused with other woods. The great hardness and fine lines of parenchyma distinguish it from other commercial species.

(f) PECAN (*Carya illinoensis*), also known as sweet pecan (western half of D and E).

Although pecan is a species of hickory in the botanical sense, it belongs to a group distinct from the true hickories (see above) and its wood is somewhat lighter in weight, softer and less tough, on the average. It, however, is suitable for uses where a strong wood, but not the high degree of toughness characteristic of the true hickories, is desired. Concomitant with its lower density, it also shrinks less.

The wood of pecan resembles that of true hickory closely in structure and color, although the pores decrease more gradually in size from the inner to the outer part of the annual ring, making the wood less distinctly ring porous (fig. 2–14). The heartwood also is more reddish in color, as a rule, although both of these features often are not sufficiently distinct to distinguish positively the wood of pecan from that of the true hickories.

(g) BLACK WALNUT (*Juglans nigra*) (B, D, and northern half of E).

Black walnut is heavy, hard, and usually straight-grained. The heartwood has a rich chocolate-brown color. The sapwood is nearly white except when darkened by steaming.

The annual rings are failry distinct, for the pores in the springwood gradually decrease in size toward the outer limit of each annual ring. Most of the pores are visible without a lens, but the rays are very fine (fig. 2–15).

The color and distinct pores are usually sufficient to distinguish black walnut from all other woods.

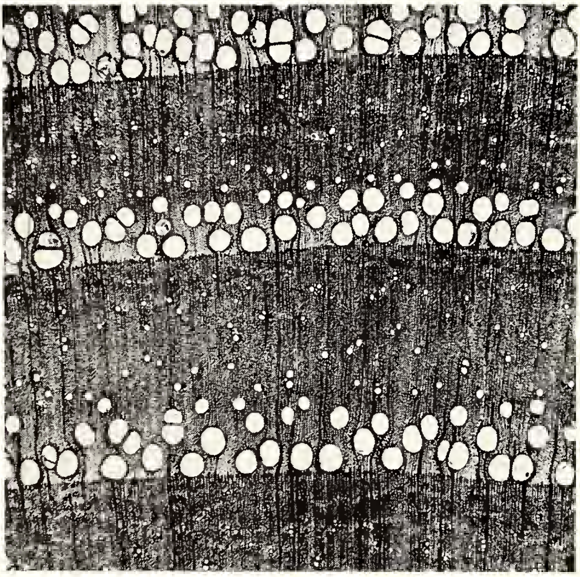

FIGURE 2-12.—White ash. Cross section magnified 15 diameters.

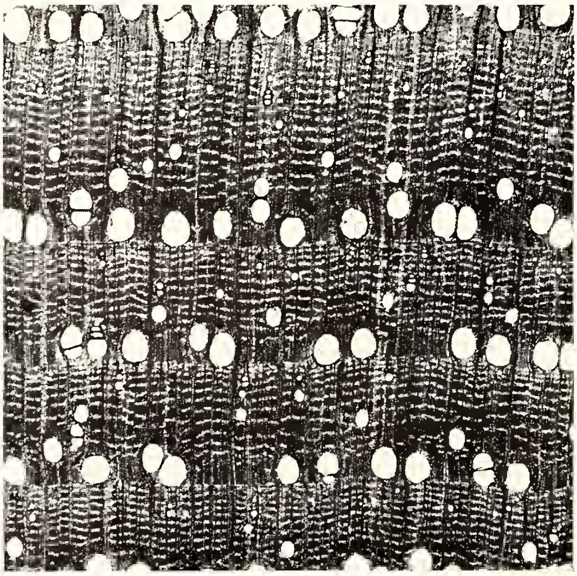

FIGURE 2-13.—Shagbark hickory Cross section magnified 15 diameters.

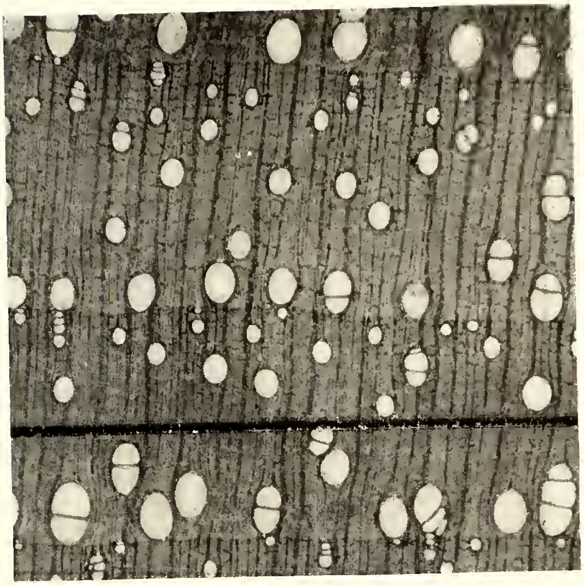

FIGURE 2-14.—Pecan. Cross section magnified 15 diameters.

FIGURE 2-15.—Black walnut. Cross section magnified 15 diameters.

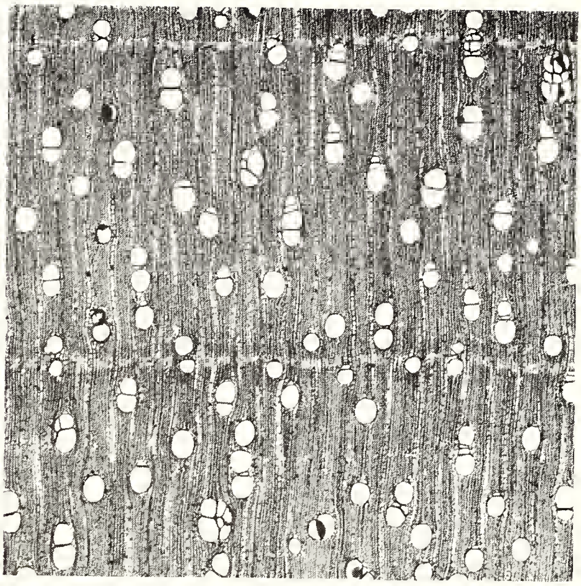

FIGURE 2-16.—Mahogany. Cross section magnified 15 diameters.

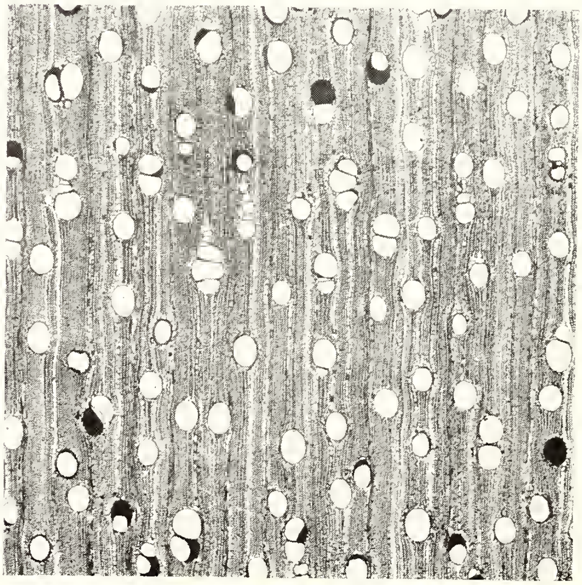

FIGURE 2-17.—Khaya. Cross section magnified 15 diameters

(h) MAHOGANY (*Swietenia spp.*) (native in southern Florida, Mexico, Central America, northern South America, and the West Indies).

Mahogany has a lustrous reddish-brown appearance, turning darker on exposure to light. It varies greatly in weight. The lighter pieces are often classed separately as "baywood." The wood is practically odorless and tasteless.

The growth rings (probably annual rings), which are defined by light-colored lines, are widely variable in width from one thirty-second to one-half inch or more (fig. 2–16). The pores are plainly visible without a lens and uniformly distributed throughout the growth ring, appearing as grooves on the longitudinal surfaces. Numerous pores contain dark, amber-colored gum. The rays are also distinct without a lens.

Khaya resembles mahogany more than any other wood. It has about the same color, and the pores are fully as distinct without a lens, but the fine, light-colored lines which define the growth rings are missing, thus affording an easy method of distinguishing the two woods. (Compare figs. 2–16 and 2–17.)

Sweetgum and birch can be stained so as to imitate mahogany surprisingly well, but on close inspection it will be found that the pores of sweetgum and birch are not distinctly visible without a lens.

(i) KHAYA (*Khaya spp.*) (West Coast of Africa).

Khaya, frequently called "African mahogany" in the trade, resembles mahogany in color, structure, and properties but differs in having slightly larger pores and no well-defined growth rings (fig. 2–17). Occasionally narrow zones of less porous wood occur, but these must not be confused with the sharply defined white lines found in mahogany. The weight of the two woods is similar, although mahogany averages a little heavier.

Like mahogany, khaya has pores plainly visible without a lens, many of the pores containing a dark amber-colored gum.

(j) AMERICAN BEECH (*Fagus grandifolia*—formerly *Fagus atropunicea*) (A, B, D, E, and eastern half of C).

American beech is a heavy, hard wood, without characteristic odor or taste. The heartwood has a reddish tinge, varying from light to moderately dark. The sapwood is usually several inches wide and passes gradually into the heartwood.

The pores are invisible without a lens and decrease in size, slightly and gradually, from the inner to the outer portion of each ring (fig. 2–18).

Some of the rays are broad, being fully twice as wide as the largest pores on cross sections. On radial surfaces the larger ones appear as conspicuous reddish-brown "flakes," and on tangential surfaces as darker dashes, measuring about one-eighth inch with the grain. The other rays are very fine.

Maple resembles beech, except that in maple the widest rays are about the same width as the largest pores and not so conspicuous on the radial surface. American sycamore resembles beech in structure; but all the rays in sycamore are wide and therefore appear more numerous, and the wood is considerably lighter in weight.

(k) AMERICAN SYCAMORE (*Platanus occidentalis*), sometimes called plane. (Occurs in all States east of the Great Plains.)

The wood of American sycamore is moderately heavy, being just slightly heavier than sweetgum. It usually has interlocked grain and is subject to shake, especially in large trees. The pale-reddish sapwood is from 1½ to 3 inches wide and merges gradually into the reddish-brown heartwood. It is without characteristic odor or taste.

The annual rings are, as a rule, distinct, being defined by a narrow, more light colored band in the outer part of each ring. The pores are not visible without a lens and fairly uniform in size, except that they are slightly smaller in the extreme outer portions of the annual rings.

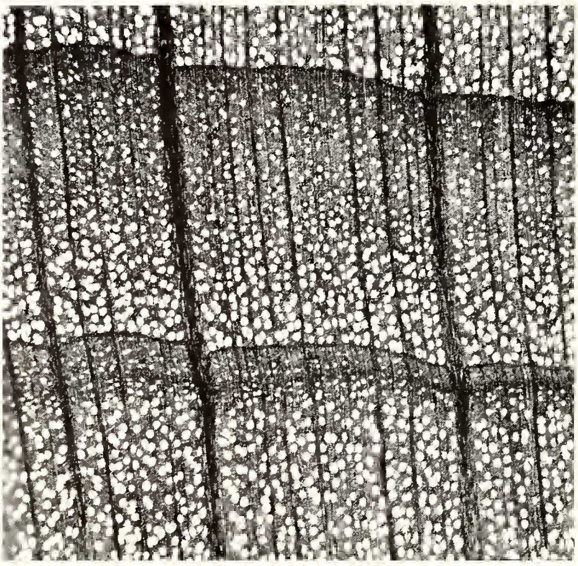

FIGURE 2-18.—American beech. Cross section magnified 15 diameters.

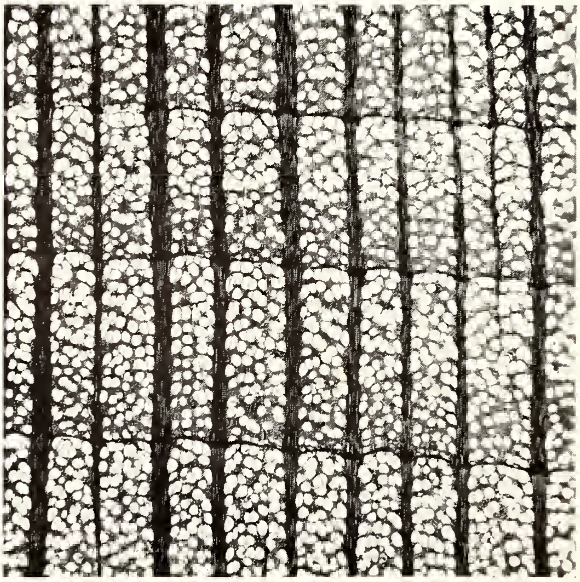

FIGURE 2-19.—American sycamore. Cross section magnified 15 diameters.

A striking characteristic of sycamore is the numerous relatively large rays conspicuous on smoothly cut end surfaces (fig. 2–19) and as darker reddish-brown "flakes" up to three-sixteenths inch along the grain on radially cut lumber and veneer.

(l) Black Cherry (*Prunus serotina*) (A, B, C, D, E).

The wood of black cherry is moderatly heavy, fairly straight-grained, and without characteristic odor or taste. The sapwood is narrow. The heartwood has a lustrous, reddish-brown color.

The annual rings are fairly well defined on account of the slightly larger pores of the springwood, which decrease in size gradually toward the outer limit of each annual ring. The pores are not visible without a lens.

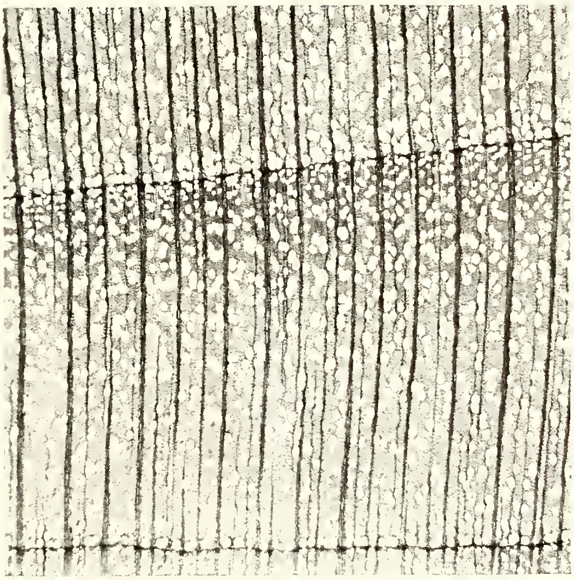

Figure 2–20.—Black cherry. Cross section magnified 15 diameters.

The rays are very distinct on the cross section, the larger ones being as wide as the largest pores (fig. 2–20).

Cherry is easily distinguished from most other woods by its color. Mahogany has a similar color, but the pores in mahogany are easily visible without a lens and frequently contain a reddish-brown gum.

(m) The Maples.

Sugar maple (*Acer saccharum*) (A, B, C, D).
Black maple (*Acer nigrum*) (B, D).
Red maple (*Acer rubrum*) (A, B, C, D, E).
Silver maple (*Acer saccharinum*) (A, B, D, E, and southern half of C).

Sugar maple and black maple, both classed as "hard maple," are heavy, hard, and difficult to cut across the grain. In these respects they differ from silver maple and red maple, which are classed as "soft maple," and are not quite so heavy and hard, although red maple is heavier and harder than silver maple. The following ranges in specific gravity have been found in these species (table 2–2):

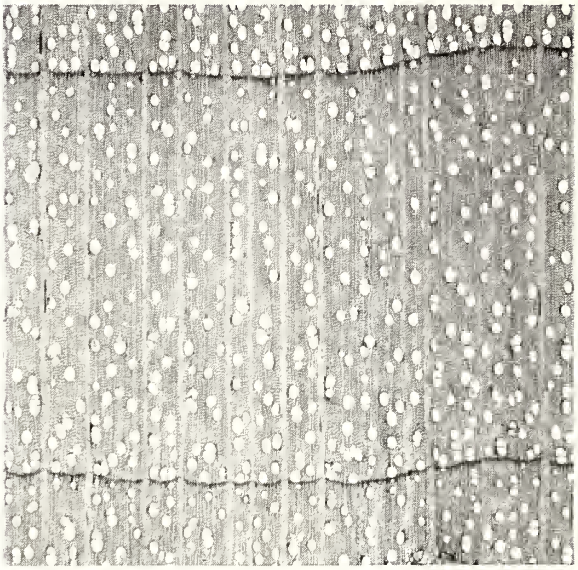

FIGURE 2-21.—Red maple. Cross section magnified 15 diameters. Pith fleck in lower right-hand quarter.

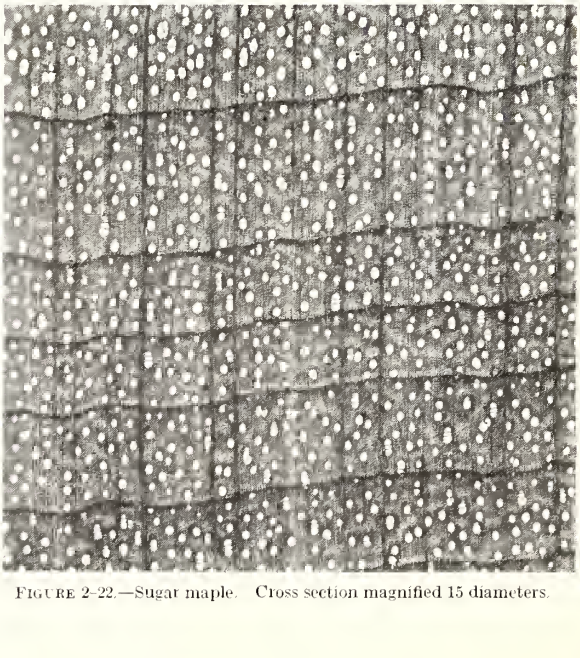

FIGURE 2-22.—Sugar maple. Cross section magnified 15 diameters.

Table 2-2.—*Specific gravity values of four maples*

Species	Specific gravity based on weight when oven dry and volume—					
	When green			When oven dry		
	Minimum	Average	Maximum	Minimum	Average	Maximum
Sugar maple	0.49	0.56	0.77	0.58	0.68	0.86
Black maple [1]	.49	.52	.57	.56	.62	.67
Red maple	.44	.49	.53	.50	.55	.61
Silver maple	.38	.44	.52	.42	.51	.61

[1] Data available on only a small number of specimens. Further tests may give appreciably different values.

The sapwood is wide in all the maples and is often sold separately as "white maple." The heartwood is light reddish-brown, without characteristic odor or taste.

The annual rings are defined by a thin reddish layer usually conspicuous on dressed longitudinal surfaces.

The pores are all very small and uniformly distributed throughout the annual rings (figs. 2-21 and 2-22).

The rays are very distinct without a lens, and under a lens the largest ones appear fully as wide as the largest pores. On radial surfaces the rays are conspicuous as small reddish-brown "flakes" about one thirty-second to one-sixteenth inch wide with the grain. In sugar maple only part of the rays are as wide as the pores; the others are very fine, being barely visible with a lens. In both the soft maples nearly all the rays appear broad, although usually not quite so broad as the large ones of sugar maple. They give the appearance, however, of being more numerous. This is a rather fine distinction, and an inspector should have samples for comparison.

Birch and beech resemble maple somewhat, although a little experience with the woods will readily show the difference. Birch has larger pores, visible as fine grooves on dressed surfaces, and the rays on the cross section are not distinctly visible without a lens. In beech some of the rays are very conspicuous, being fully twice as wide as the largest pores, and the pores decrease in size and number toward the outer part of each annual ring.

(n) The Birches.

Yellow birch (*Betula lutea*) (A, B, C).

Sweet birch (*Betula lenta*), also known as black birch and cherry birch (A, B, and eastern half of D).

Alaska birch (*Betula neoalaskana*) (Alaska).

Paper birch (*Betula papyrifera*) (A, C, and northern part of B).

The woods of the yellow birch and sweet birch are so much alike that as a rule no distinction is made between the two, although sweet birch is somewhat heavier. The yellow birch is the more abundant of the two. The heartwood of both is marketed as "red birch" and the sapwood as "yellow birch." The wood is heavy to very heavy, straight or curly grained.

Alaska birch and paper birch are similar in properties, both being moderately heavy and moderately hard.

The sapwood of all the birches is comparatively wide and practically white; the heartwood is light to dark reddish brown. The heartwood of Alaska and paper birch in trees of commercial size frequently is infected with decay. Brich wood is practically odorless and tasteless.

The annual rings are sharply but not conspicuously defined by a thin layer of denser tissue in the outer part of each annual ring (fig. 2–23). The pores are of almost uniform size throughout the annual rings and barely visible, under a good light, on a very smoothly cut cross section. On dressed longitudinal surfaces the pores appear as fine grooves. The rays are not visible without a lens, their diameter being much smaller than that of the largest pores.

Yellow birch and sweet birch cannot positively be distinguished from each other by means of the wood alone. Neither can Alaska birch and paper birch be distinguished from each other, but they can in many cases be differentiated from yellow and sweet birch by their lower weight, although there is some overlapping, as is indicated by the following ranges in specific gravity of the wood of these species at heights in the tree 8 to 16 feet above ground (table 2–3):

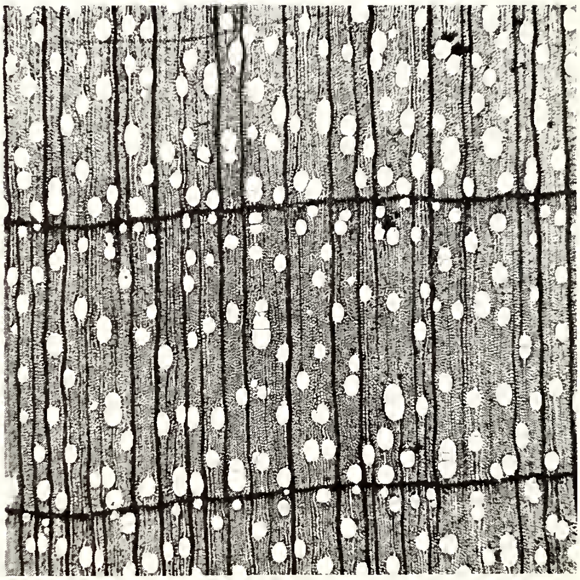
FIGURE 2–23.—Yellow birch. Cross section magnified 15 diameters.

TABLE 2–3.—*Specific gravity values for four birches*

Species	Specific gravity based on weight when oven dry and volume—					
	When green			When oven dry		
	Minimum	Average	Maximum	Minimum	Average	Maximum
Sweet birch	0. 53	0. 60	0. 68	0. 60	0. 71	0. 81
Yellow birch	. 48	. 55	. 61	. 55	. 66	. 74
Alaska birch	. 44	. 49	. 55	. 51	. 59	. 66
Paper birch	. 42	. 48	. 54	. 54	. 60	. 66

Paper birch usually has numerous pith flecks (sec. 2.30) which are absent or comparatively scarce in yellow and sweet birch, as a rule, although they sometimes are common in the latter two species and scarce in paper birch. River birch (*Betula nigra*), which is rarely cut into lumber, also has numerous pith flecks, as a rule.

Maple is occasionally confused with birch, but the two are easily distinguished by the fact that in maple the pores are much smaller and the rays wider, the latter being very distinct without a lens.

(o) SWEETGUM (*Liquidambar styraciflua*), also known as red gum (Southern parts of B, D, E).

Sweetgum is moderately heavy, with somewhat interlocked grain, and without characteristic odor or taste. The sapwood (sold as "sapgum") is highly variable in width. It is white, with a pinkish hue, or often blued with sap stain. The heartwood is reddish brown, often with irregular darker streaks. The wood has a very uniform structure. The annual rings and pores are not distinct to the unaided eye, but the rays are fairly distinct without a lens (fig. 2–24).

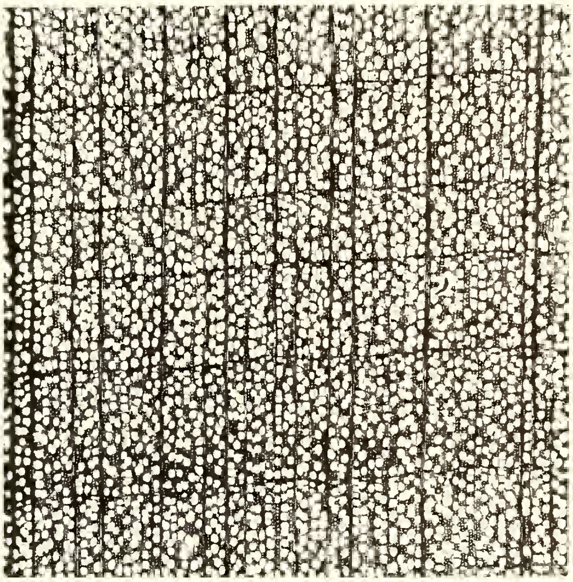

FIGURE 2–24.—Sweetgum. Cross section magnified 15 diameters.

The fine, uniform texture, interlocked grain, and reddish-brown color are usually sufficient to distinguish sweetgum from other woods.

(p) YELLOWPOPLAR (*Liriodendron tulipifera*), also known as whitewood, tulip poplar, tuliptree (B, D, E).

Yellowpoplar is moderately light, straight grained, and without characteristic odor or taste. The sapwood is from 1 inch to several inches wide. The heartwood is light to moderately dark yellowish brown with a greenish tinge, occasionally purplish brown.

The annual rings are limited by light-colored lines. The pores are evenly distributed throughout the annual ring, and are too small to be visible with the unaided eye. The rays are distinct without a lens but narrower than the largest pores (fig. 2–25). The heavier grades of yellowpoplar are difficult to distinguish from magnolia and cucumbertree.

(q) SOUTHERN MAGNOLIA (*Magnolia grandiflora*), also called evergreen magnolia. (Coastal Plain form southern North Carolina to eastern Texas.)

This species is much like yellowpoplar in color and structure but is appreciably heavier and stronger. The heartwood normally is greenish yellow or brown, but occasionally it exhibits various shades of purple to almost black. It has no characteristic odor or taste.

The annual rings are fairly distinct on smooth surfaces, being defined by narrow, whitish lines. The pores are too small to be visible without a lens, uniform in size, and evenly distributed in the annual ring. The rays are barely visible without a lens, being light colored and about as wide as the largest pores.

A similar species of magnolia, called sweetbay (*Magnolia virginiana*), growing in the southeastern portion of the country from southern New England to Texas, is of some commercial importance. No test data on the wood are available, but it is reported to be similar to southern magnolia.

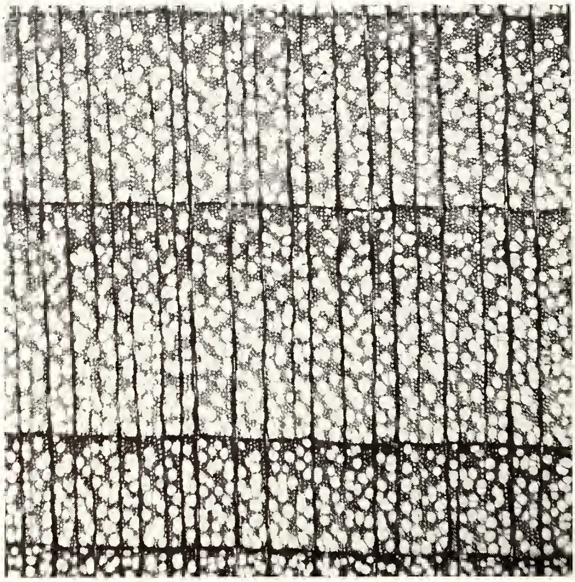

FIGURE 2–25.—Yellowpoplar. Cross section magnified 15 diameters.

CUCUMBERTREE (*Magnolia acuminata*) is easily confused with yellowpoplar as well as with other species of magnolia, although it averages somewhat heavier than yellowpoplar. It is not quite so heavy as southern magnolia and has narrower rays. It is frequently sold as yellowpoplar. It grows in the same region, except in Florida and along the South Atlantic coast. (It can be positively distinguished from yellowpoplar and other species of magnolia with a compound microscope.)

(r) BASSWOOD (*Tilia glabra*, *Tilia heterophylla*, and other species), also known as linden (A, B, C, D, E).

Basswood is a light, soft, straight-grained wood with a creamy white or very pale brown color. The heartwood is not clearly defined from the sapwood. Occasionally the heartwood has an abnormal reddish-brown color. It is without taste, but has a slight characteristic odor even when dry. The wood is diffuse porous, the pores being invisible without a lens. The rays are fairly distinct on the end surface and often conspicuous on the radial surface (fig. 2–26).

(s) COTTONWOOD (*Populus spp.*) (B, C, D, E, F).

Cottonwood is light to moderately light, soft, and more or less cross-grained. The straighter-grained lumber warps less and is believed to come from old, slow-growing trees known as "yellow cottonwood" in distinction from the "white cottonwood," which usually has wide annual rings and is more subject to warping. Cottonwood is without taste but has a slight characteristic odor. The heartwood, which is light grayish brown, is not clearly defined from the sapwood.

The pores, which are barely visible to the naked eye, are very numerous and of about uniform size throughout the annual ring. The rays are very fine, barely visible with a lens (fig. 2–27).

Light-weight water tupelo resembles cottonwood but has smaller pores. Yellow-poplar is similar in weight and hardness, but its greenish tinge usually distinguishes it. Basswood has a more creamy-white color, smaller pores, and more distinct rays.

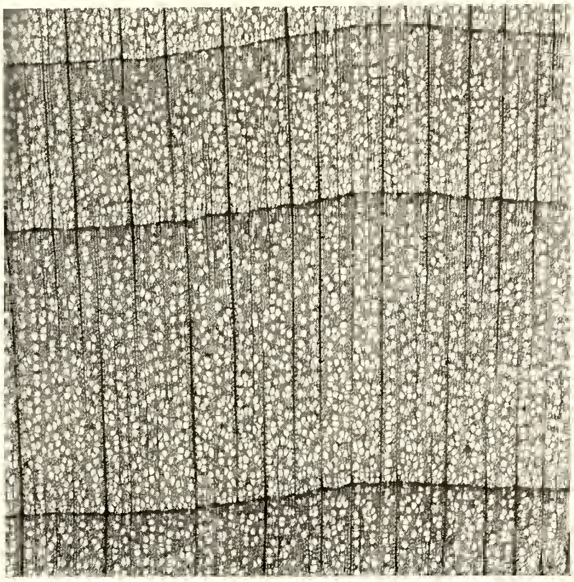

FIGURE 2-26.—Basswood. Cross section magnified 15 diameters.

(t) WATER TUPELO (*Nyssa aquatica*), also known as tupelo gum and tupelo. (Coastal and Mississippi bottomlands of E.)

This is one of the most variable of native species of wood. Trees growing in inundated swamps usually have swelled butts which contain exceedingly light wood, whereas 10 to 16 feet above the ground the wood may be normal. Ranges in specific gravity from 0.19 to 0.52 have been found in trunks, and even lighter wood is produced in the roots of this species in wet situations. The wood characteristically has interlocked grain.

The wide sapwood is dead white in color, and the heartwood is light brownish gray. It is without characteristic odor or taste.

The pores are very small (invisible without a lens), rather uniform in size, and fairly evenly distributed throughout the annual ring, which is bounded by a narrow line sometimes difficult to see clearly. Occasionally three or more pores are adjacent in radial rows, as seen with a hand lens on a smoothly cut surface, a fact which distinguishes this wood from the sapwood of sweetgum, in which the pores are not in distinct radial rows. Compare figures 2–24 and 2–28. The rays are very fine, a fact

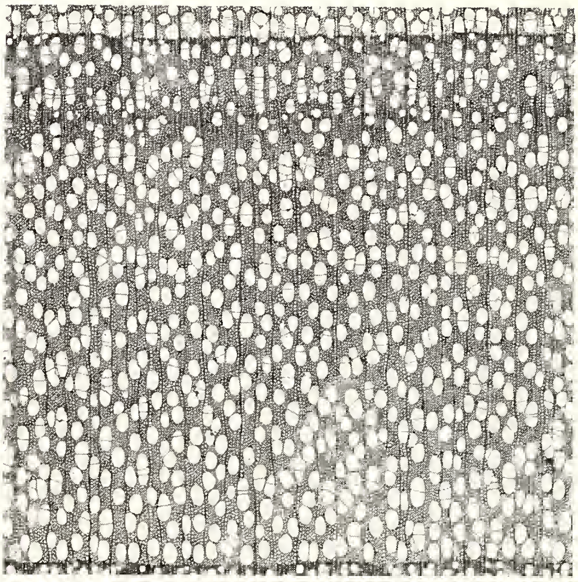

FIGURE 2–27.—Cottonwood. Cross section magnified 15 diameters.

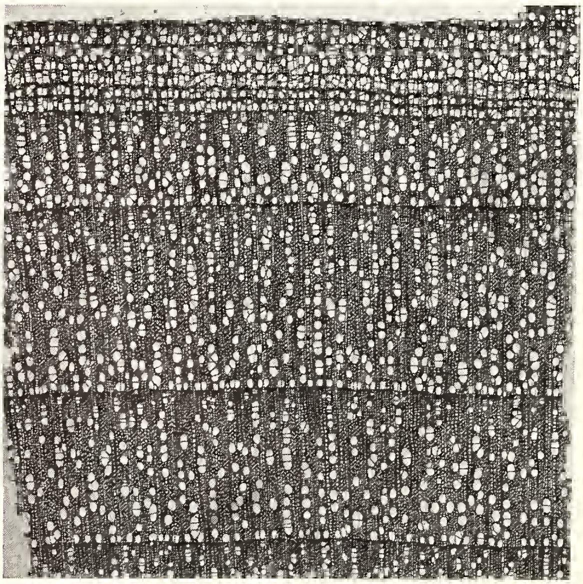

FIGURE 2–28.—Water tupelo. Cross section magnified 15 diameters.

which, together with the small pores and inconspicuous annual ring boundaries, makes the wood unusually featureless except for its interlocked grain.

The wood of swamp tupelo (*Nyssa biflora*), which grows along the coast from Maryland to Texas, is indistinguishable from that of water tupelo and is usually marketed as such. Blackgum (*Nyssa sylvatica*) does not produce as light wood and has darker heartwood, but even so it is difficult to distinguish from the heavier wood of the other two species.

CONIFERS

(u) THE CEDARS.

Alaska yellow-cedar (*Chamaecyparis nootkatensis*), also known as Alaska cypress (western portion of H and northward along the coast to Alaska).

FIGURE 2-29.—Port Orford white-cedar. Cross section magnified 15 diameters.

Port Orford white-cedar (*Chamaecyparis lawsoniana*), also known as "Port Orford cedar" (southwestern Oregon and northwestern California).

Northern white-cedar (*Thuja occidentalis*) (A, B, C).

Western redcedar (*Thuja plicata*) (H, northern F).

California incense-cedar (*Libocedrus decurrens*) (Oregon and California).

The wood of Port Orford white-cedar is moderately light in weight, straight-grained, and with a pungent, spicy odor and taste. The sapwood is not clearly defined from the heartwood, which is very pale brown in color.

The summerwood is not dense and hard, as in many coniferous woods, and the springwood is a little firmer than in the western redcedar, thus making Port Orford white-cedar a wood very uniform in structure and less spongy than some of the other cedars (fig. 2-29).

The odor and very light-brown color are usually enough to identify Port Orford white-cedar.

Alaska yellow-cedar is similar to Port Orford white-cedar in weight and structure but is almost clear yellow in color. The odor is less spicy, more disagreeable, but also strong and characteristic.

FIGURE 2-30.—Western redcedar. Cross section magnified 15 diameters.

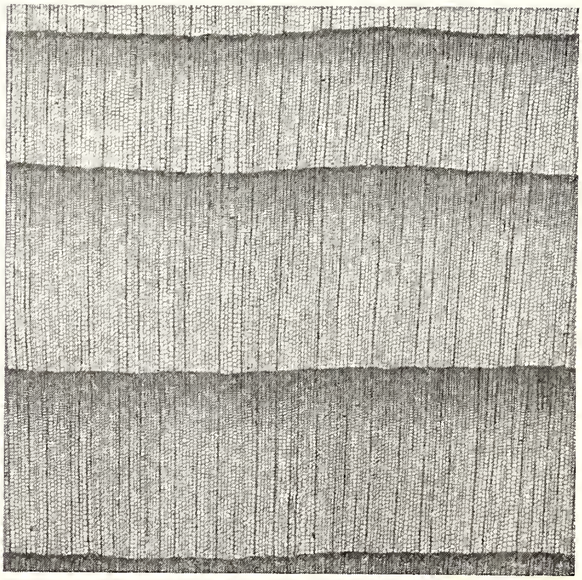

FIGURE 2-31.—California incense-cedar. Cross section magnified 15 diameters.

Western redcedar is light in weight and straight-grained. The sapwood is rarely over 1 inch wide. The heartwood is reddish brown, with the characteristic odor of cedar shingles and a somewhat bitter taste when chewed. The wood is not "pitchy" and contains no resin ducts, although it contains a slight quantity of aromatic oils.

The annual rings are distinct, moderate in width, with a thin but well-defined band of summerwood (fig. 2–30). The springwood is very soft and spongy.

Northern white-cedar resembles western redcedar in odor and taste but generally is without the reddish hue; usually it has narrower annual rings, less pronounced summerwood, and averages lighter in weight.

California incense-cedar is also very similar to western redcedar, although it has wider sapwood as a rule. Particles of amber-colored resin in the ray cells, as seen on the radial surface with a good hand lens, are abundant in California incense-cedar but almost absent in the western redcedar. In California incense-cedar (fig. 2–31) the springwood is firmer than in western redcedar, making the wood as a whole more uniform in texture. Although the odor and taste resemble those of western redcedar, they are more acrid in California incense-cedar.

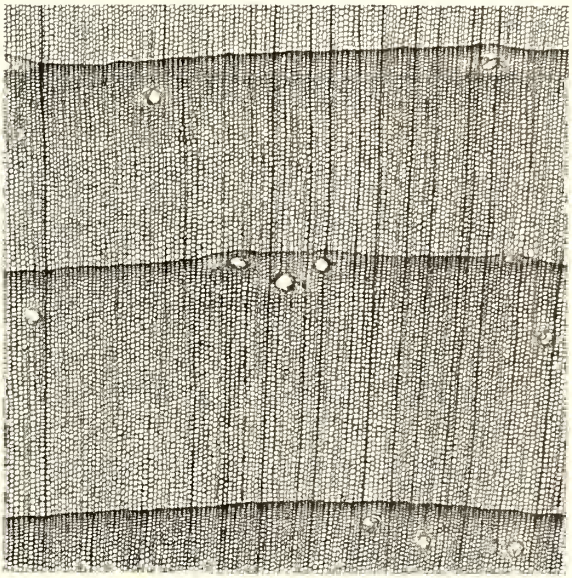

FIGURE 2–32.—Eastern white pine. Cross section magnified 15 diameters.

(v) THE WHITE PINE GROUP.

Eastern white pine (*Pinus strobus*) (A, B, C).
Western white pine (*Pinus monticola*), also known as Idaho white pine (F, H, I).
Sugar pine (*Pinus lambertiana*) (I).

Eastern and western white pine are very similar in the character of the wood. They are light to moderately light, straight-grained, and practically tasteless but have a slight, yet distinct, resinous odor. Of the two, the western species is slightly heavier. The sapwood varies from 1 to several inches in width. The heartwood is creamy brown to light reddish brown, especially reddish at knots.

The annual rings are distinct, but the summerwood is not a pronouncedly darker or appreciably harder layer. Through a lens, the resin ducts appear on the cross section as specks or minute openings (fig. 2–32). On longitudinal surfaces they usually are visible to the naked eye as yellowish-brown lines. Exudations of resin occur occasionally, especially when the wood is warmed.

Since the eastern and western white pines are very similar in appearance and properties, it is not necessary to distinguish between the two commercially. The outer portion of ponderosa pine logs usually has narrow annual rings, with a very thin layer of summerwood approximating the white pines in appearance, and is sometimes sold as "white pine." It usually can be distinguished, however, by its horny, glistening layer of summerwood, especially in the wider rings, in which it is more conspicuous. (Compare figs. 2–32 and 2–34.) Often the summerwood is more distinct on the longitudinal surface. In a shipment of ponderosa pine lumber, numerous boards with conspicuous layers of summerwood may usually be found.

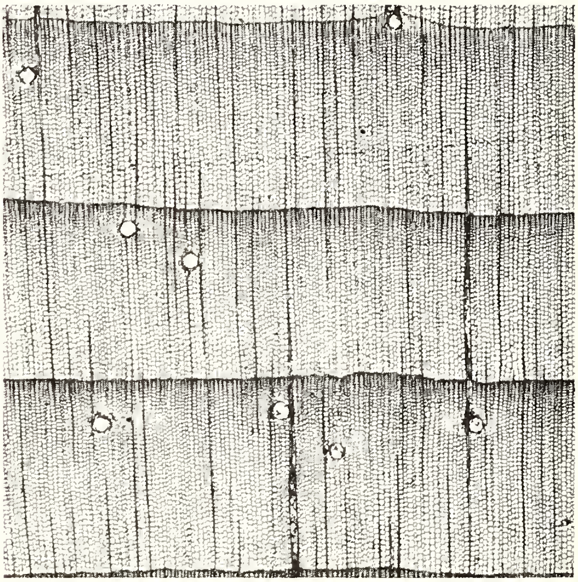

FIGURE 2–33.—Sugar pine. Cross section magnified 15 diameters.

Sugar pine is very much like other species of the white pine group in structure and properties. The sapwood is from 1 to several inches wide. The heartwood is very light brown, only slightly darker than the sapwood and practically never reddish, as is the case quite often in the white pines. Brown stain, which is common, is caused by drying the lumber under certain conditions. The summerwood never appears as a horny, glistening band as in the hard pines.

The wood of sugar pine has a slightly coarser texture than that of white pine; that is, the fibrous cells and resin ducts have a greater average diameter. The distinction is rather fine, however, to use without a compound microscope (fig. 2–33). On a longitudinal surface the resin ducts usually are more conspicuous as brownish lines, but in some pieces of sugar pine they are inconspicuous, and occasionally in eastern white pine, western pine, and ponderosa pine they may be just as prominent as in any sugar pine.

White granular exudations with a sweetish taste are quite common in sugar pine lumber and when present are the most reliable means of distinguishing it from other pines.

(w) The Yellow Pine Group.

Ponderosa pine (*Pinus ponderosa*) (F, G, H, I).

Red pine (*Pinus resinosa*), also called Norway pine (A, northern part of B, C).

Ponderosa pine is one of the lightest and weakest woods of the yellow pine group and averages only slightly heavier than western white pine. It is more variable, however, some of the more vigorous second growth approximating southern yellow pine in structure and properties.

Red pine is somewhat heavier than ponderosa pine, on the average, and less variable in weight. The sapwood of both species varies from 2 to 4 inches in width, and the heartwood is light reddish brown, becoming darker on exposure to light. The heartwood has a distinct resinous odor, especially when freshly cut. The summerwood of both species, which is dark and hornlike, distinguishes them from species of the white pine group, although often it is very narrow, especially in ponderosa pine. (Compare figs. 2–34 and 2–35.) (Red pine is the only one of the native pines that can positively be distinguished from all other native species of pine with a compound microscope.)

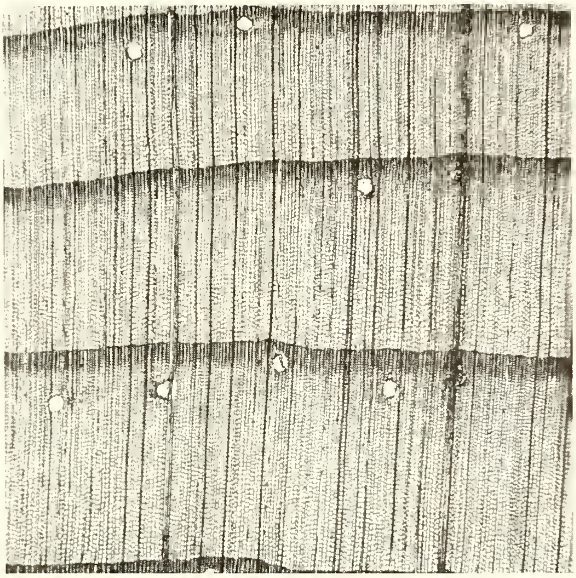

Figure 2-34.—Ponderosa pine. Cross section magnified 15 diameters.

(x) Douglas-Fir (*Pseudotsuga taxifolia*), also known as red fir, yellow fir, and "Oregon pine" (export) (F, G, H, I).

Douglas-fir differs from true firs (white fir, noble fir, balsam fir, etc.) in that it is heavier, stronger, more durable, and has resin ducts and distinctly darker heartwood. The heartwood has a reddish hue, usually quite pronounced, especially after exposure, although in old coast firs the outer part of the heartwood is less reddish and is marketed as "yellow fir." The heartwood of Douglas-fir has a characteristic odor when worked. The sapwood is from one to several inches wide.

The annual rings are made distinct by a conspicuous band of summerwood. Resin ducts are not so distinct as in the pines, usually appearing as whitish specks in the summerwood. Often several ducts are in short tangential rows, a feature not normally found in the pines. (Compare figs. 2–35 and 2–36.) Slight exudations of resin on cross sections are common or can usually be made to appear slightly by warming the wood. The wood is moderately heavy to heavy.

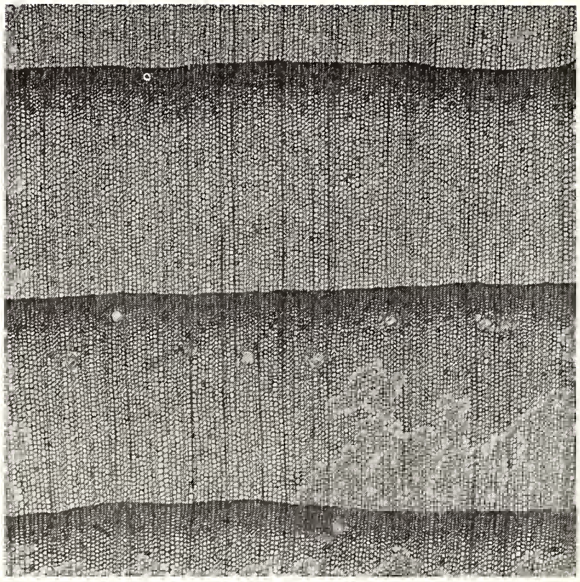

FIGURE 2-35.—Red pine. Cross section magnified 15 diameters.

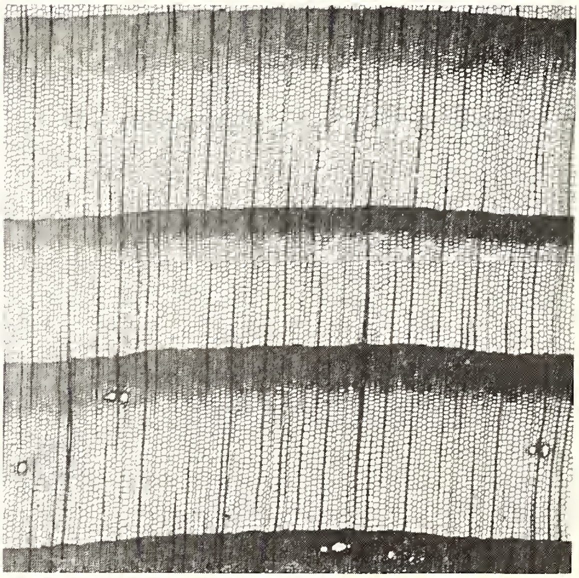

FIGURE 2-36.—Douglas-fir. Cross section magnified 15 diameters.

With a compound microscope, Douglas-fir can easily be distinguished from all other commercial woods by the presence of fine spirals in the fibers that resemble the thread in a nut. This can be seen under a microscope on a longitudinal split surface without preparing a microscopic slide.

(y) Western Larch (*Larix occidentalis*) (F, H).

Larch resembles Douglas-fir considerably but has narrower sapwood (rarely over 1 inch) and, instead of being reddish in color, the heartwood is russet brown (fig. 2–37). The resin ducts in the two species are of about the same character, although the fir is more resinous as a rule.

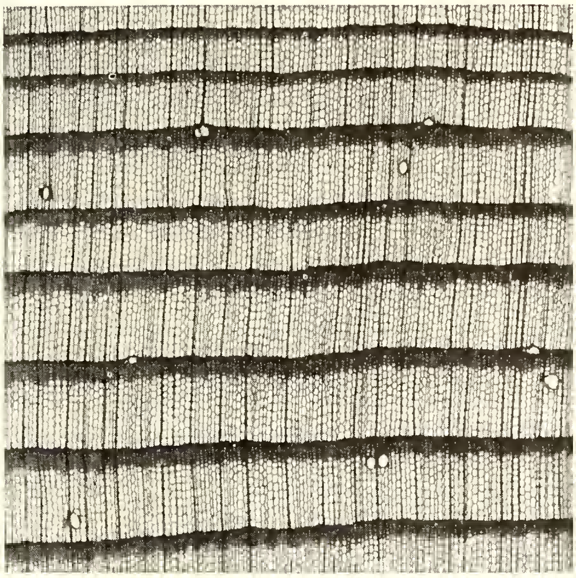

Figure 2–37.—Western larch. Cross section magnified 15 diameters.

(z) The Spruces.

White spruce (*Picea glauca*—formerly *Picea canadensis*) (A, C).
Red spruce (*Picea rubra*) (A, B).
Sitka spruce (*Picea sitchensis*) (Along coast from northern California into Alaska).

The spruces are light to moderately light, usually straight-grained woods. In the white spruce and red spruce the heartwood is as light colored as the sapwood, but in Sitka spruce the heartwood has a light reddish tinge, making it a little darker than the sapwood.

The annual rings are clearly defined by a distinct, but not very hard and horny, band of summerwood. Spruce resembles the white pines in texture, but the resin ducts are fewer and smaller in spruce (compare figs. 2–32 and 2–38), usually appearing on the cross sections as whitish specks in the summerwood and on longitudinal surfaces as faint lines. Pitch pockets are occasionally found in spruce, and slight exudations of resin occur on cuts made before the wood is seasoned.

On account of its reddish tinge, Sitka spruce might be confused with light grades of Douglas-fir. The fir, however, has wider summerwood, except in very narrow rings; therefore, rings of average width should be compared. Split or smoothly dressed tangential surfaces of Sitka spruce usually have numerous slight indentations which give it a "pocked" appearance never found in Douglas-fir (fig. 2–39). This characteristic is more pronounced in material with narrow annual

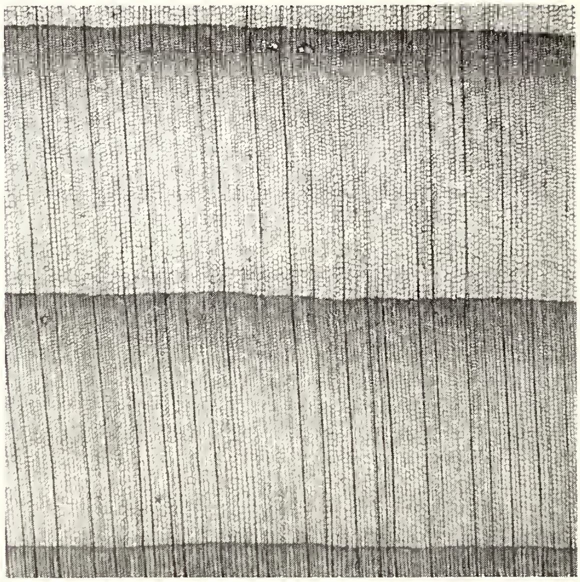

FIGURE 2-38.—Sitka spruce. Cross section magnified 15 diameters.

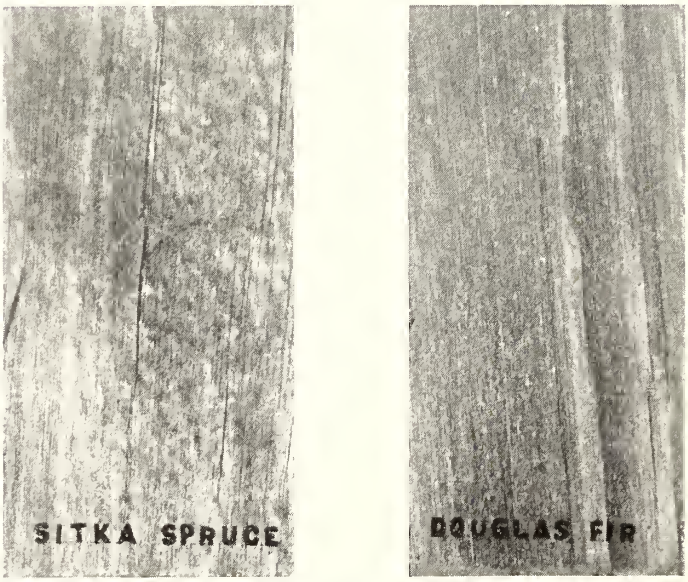

FIGURE 2-39.—Split tangential surfaces of Sitka spruce and Douglas-fir showing the "pocked" appearance of the spruce, not found in Douglas-fir. This characteristic is most pronounced in Sitka spruce with narrow rings and is almost entirely absent in very wide-ringed material.

rings and may be missing entirely in wide-ringed spruce, especially that near the center of the tree. Occasionally the eastern spruces also show this uneven tangential surface to a slight extent. Some ponderosa pine trees also develop this "pocked" appearance of the wood, but the pine can be distinguished by the large and more numerous resin ducts and darker heartwood.

Engelmann spruce (*Picea engelmanni*) is a common tree of the Rocky Mountain and Cascade Ranges. That growing in the United States averages lighter in weight than Sitka spruce and therefore a smaller percentage is of suitable strength for use in aircraft. The wood of Engelmann spruce cannot be distinguished from that of white and red spruce by its color or cellular structure.

(aa) THE CYPRESSES.

Baldcypress (*Taxodium distichum*) (E).
Pondcypress (*Taxodium ascendens*) (E).

These two species cannot be distinguished by means of the wood alone. They are highly variable in color and weight. Commercially, the wood is often classified as "white," "yellow," "red," and "black" cypress according to color, but these are arbitrary terms without definite meaning. As a rule, the darker grades are heavier, but that is not always the case. The heartwood has a characteristic rancid odor when fresh. In dry wood the odor is less pronounced, but can often be detected by whittling or, better yet, sawing the wood and holding the sawdust to the nostrils. The wood is without characteristic taste. The weight varies from moderately light to moderately heavy.

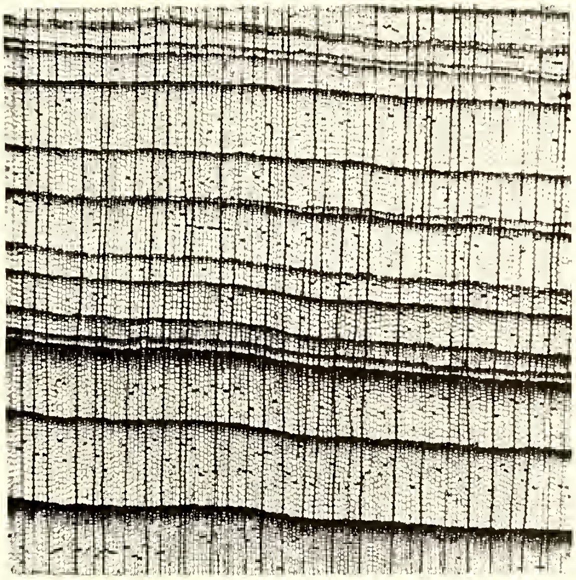

FIGURE 2-40.—Baldcypress. Cross section magnified 15 diameters.

The annual rings usually are irregular in width and outline (fig. 2-40). The summerwood is very distinct but narrow, although often wider than in the cedars. Cypress wood feels greasy or waxy to the touch, especially the heavier and darker kinds. Resin ducts and exudations of resin are absent.

Baldcypress resembles the cedars and redwood somewhat; but the cedars have an aromatic odor and spicy taste, and redwood is tasteless and odorless.

(bb) REDWOOD (*Sequoia sempervirens*). (Northwestern portion of I.)

Redwood can easily be distinguished from other native species (except giant sequoia, which grows in the Sierra Nevada Mountains but is not commercially important) by its moderately light, reddish brown wood without odor or taste. Western redcedar heartwood, with which it is most easily confused, has pronounced odor and taste. It has no pores or resin ducts (fig. 2–41). The summerwood, although usually narrow, is rather dense. The color may vary from light to dark shades of reddish brown.

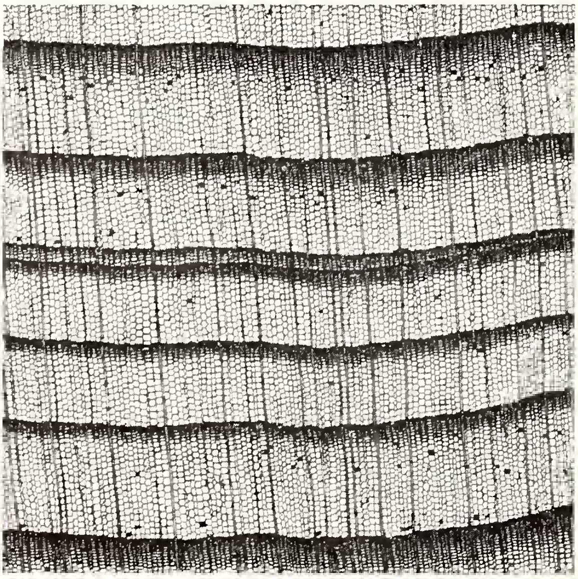

FIGURE 2–41.—Redwood. Cross section magnified 15 diameters.

(cc) THE TRUE FIRS.

Noble fir (*Abies nobilis*) (H).
California red fir (*Abies magnifica*) (I, southern H).
Pacific silver fir (*Abies amabilis*) Western half of H and I and along the coast to southern tip of Alaska).
White fir (*Abies concolor*) (G, H, I).
Grand fir (*Abies grandis*) (H, and northwestern parts of F and I).

These and other species of lesser importance belong to the true, or balsam fir group, which is distinct from Douglas-fir. Both heartwood and sapwood of white fir, grand fir, and Pacific silver fir are nearly white in color—more specifically, the springwood is white but the summerwood is brownish with a lavender tinge. In noble fir (fig. 2–42) and California red fir the springwood as well as the summerwood has a faint reddish tinge, making it difficult to distinguish these species from western hemlock, which they also resemble closely in structure. In fact, it often is not possible to distinguish these species without a compound microscope. Although the summerwood is distinct in all of these species, it is not as hard as in Douglas-fir. The wood is light to moderately light in weight.

Resin ducts are normally absent in the true firs, although occasionally tangential rows of traumatic ducts (abnormal ducts due to an injury) are present, but exudations of resin rarely occur.

The wood is practically odorless and tasteless.

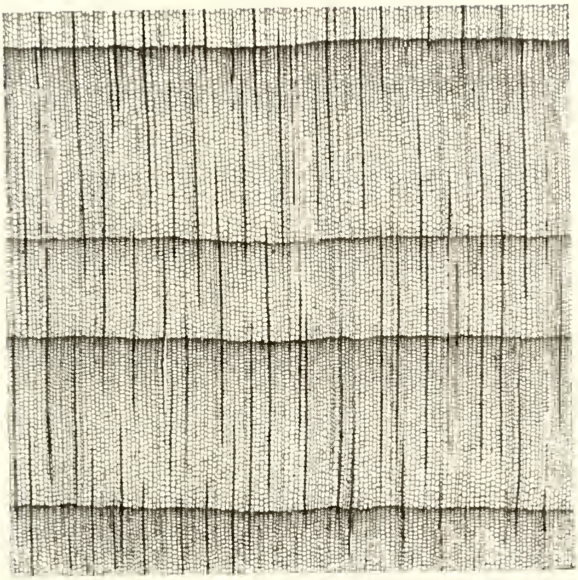

FIGURE 2-42.—Noble fir. Cross section magnified 15 diameters.

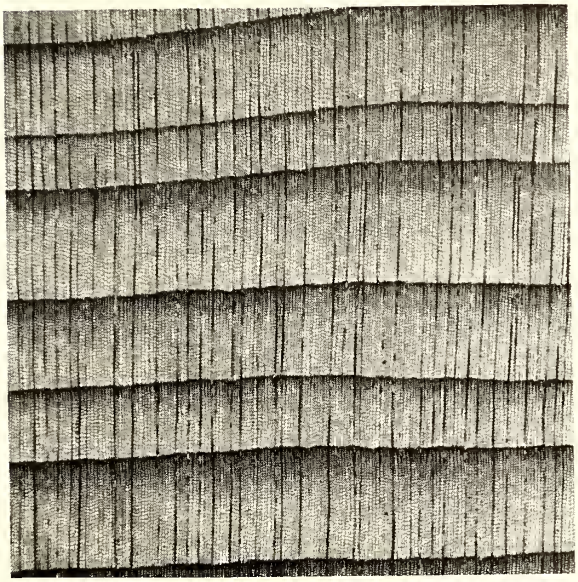

FIGURE 2-43.—Western hemlock. Cross section magnified 15 diameters.

(dd) Western Hemlock (*Tsuga heterophylla*). (F, H, and northwestern California.)

This is a moderately light, straight-grained species. The sapwood is not readily distinguished from the heartwood, which is pale brown in color with a reddish tinge. Narrow bands of summerwood, which are not very hard, clearly define the annual rings (fig. 2–43). The springwood as well as the summerwood is slightly reddish, which makes it difficult to distinguish hemlock from noble fir. Resin ducts are normally absent, although frequently tangential rows of traumatic resin ducts are found, appearing in the form of dark lines on transverse and longitudinal sections. Resin does not ordinarily exude from these ducts, and the wood may be said to be non-resinous for all practical purposes.

2.16. Key for the Identification of Wood Useful in the Construction of Airplanes

(Unless otherwise directed, all observations as to structure should be made on cross sections of rings of average width cut smoothly with a sharp knife; and all observations as to color should be made on freshly cut longitudinal surfaces of the heartwood. A lens with a magnifying power of from 8 to 15 diameters should be used.)

Hardwoods

I. Wood with pores. The pores are conspicuously larger than the surrounding cells, although in some species they are not visible without magnification. Neither the pores nor the fiber cells are in continuous radial rows. (For "Wood without pores," see II, p. 47.)

A. Ring-porous woods; that is, the pores at the beginning of each annual ring are comparatively large, forming a distinct porous ring, and decrease in size more or less abruptly toward the summerwood. (For "Diffuse-porous woods," see B, p. 45.)

1. Summerwood figured with irregular V-shaped patches of pores and light-colored tissue extending across the annual rings and visible without a lens on a smoothly cut cross section. Many rays very broad and conspicuous. Wood heavy to very heavy.

The Oaks.

a. Pores in the summerwood very small and so numerous as to be exceedingly difficult to count under a lens; pores in the springwood of the heartwood more or less completely plugged with tyloses; except in chestnut oak, in which they are more open. Heartwood brown, usually without reddish tinge.

The White Oak Group, page 13.

b. Pores in the summerwood larger, distinctly visible with (sometimes without) a hand lens, and not so numerous but that they can readily be counted under a lens; pores in the springwood mostly open; tyloses not abundant. Heartwood brown, usually with reddish tinge.

The Red Oak Group, page 15.

2. Summerwood figured with long or short wavy bands running more or less parallel with the annual rings, and visible without a lens on a smoothly cut cross section. Rays not distinct without a lens.

a. Careful examination with a hand lens shows that the pores of the summerwood are very numerous and joined so as to form more or less wavy tangential bands. Grain frequently interlocked.

The Elms.

a_1. Large pores in the springwood usually in one row, except in very wide rings. Heartwood light reddish brown. Sapwood usually more than 1 inch wide.

a_2. Rows of pores in the springwood conspicuous because they are large enough to be plainly visible without a lens; they are mostly open, containing only a few tyloses; and they are fairly close together. Wood moderately heavy; fairly easy to cut.

American Elm, page 15.

b_2. Rows of pores in the springwood inconspicuous because they are small, being barely visible without a lens; they are closed with tyloses, especially in the heartwood; and they often are somewhat separated. Wood heavy; difficult to cut.

Rock Elm, page 15.
Cedar Elm, page 15.

b₁. Large pores in springwood in several rows; mostly open, containing few tyloses. Heartwood deep reddish brown. Sapwood usually less than 1 inch wide. Wood moderately heavy.

SLIPPERY ELM, page 15.

b. Careful examination with a hand lens shows the pores of the summerwood to be few and isolated (or occasionally in radial rows of two or three), but surrounded by light-colored tissue (parenchyma), which projects more or less tangentially, occasionally connecting pores widely separated, especially toward the outer portion of the annual rings. Grain usually straight.

THE ASHES.

a₁. Projections of light-colored tissue from the pores of the outer summerwood comparatively long and distinct. Heartwood grayish brown, occasionally with reddish tinge. Sapwood wide and usually present in wide boards. Wood heavy.

GREEN ASH, page 17.
WHITE ASH, page 17.

b₁. Projections of light-colored tissue from the pores of the outer summerwood short, often absent. Heartwood grayish brown. Sapwood usually less than 1 inch wide and therefore scarce in lumber. Wood moderately heavy.

BLACK ASH, page 17.

3. Summerwood not figured with radial or tangential bands distinctly visible without a lens. Pores in the summerwood comparatively few and isolated or in radial rows of two or three. Rays not distinctly visible without a lens.

a. Numerous continuous, fine, light-colored, tangential lines (parenchyma) independent of the pores in each annual ring plainly visible under a lens. Sapwood wide; heartwood reddish brown. Wood very heavy.

a₁. Pores decreasing in size abruptly from springwood to summerwood.

THE TRUE HICKORIES, page 19.

b₁. Pores decreasing in size more or less gradually from springwood to summerwood.

PECAN, page 19.

b. No fine lines of parenchyma visible except occasional short projections of parenchyma from the outermost pores of the summerwood. Sapwood narrow; heartwood grayish brown. Wood moderately heavy.

BLACK ASH, page 17.

B. Diffuse-porous woods; that is, the pores are of about uniform size and evenly distributed throughout each annual ring, or if they are slightly larger and more numerous in the springwood they gradually decrease in size and number toward the outer edge of the ring.

1. Pores comparatively large and conspicuous, plainly visible without a lens.

a. Heartwood dark chocolate brown. Pores usually contain tyloses. Wood heavy.

BLACK WALNUT, page 19.

b. Heartwood reddish brown. Many pores partly filled with dark amber-colored gum. Wood moderately heavy to heavy.

a₁. Fine, light-colored, continuous tangential lines varying from one thirty-second to one-half inch apart, probably borders of annual rings, plainly visible without a lens.

MAHOGANY, page 23.

b₁. No fine, light-colored, tangential lines present, although lighter colored zones without sharp boundaries may be present.

KHAYA, or "AFRICAN MAHOGANY" page 23.

2. Pores not plainly visible without a lens (although barely visible under favorable conditions in birch and cottonwood).

a. Largest rays fully twice as wide as the largest pores; visible on the radial surfaces as conspicuous "flakes." Heartwood light reddish brown.

a₁. Practically all rays on transverse and tangential surfaces broad and appearing crowded; up to three-sixteenths inch wide with the grain on radial or tangential surfaces. Pores crowded, decreasing little, if any, in size at extreme outer portion of the annual rings. Wood moderately heavy.

AMERICAN SYCAMORE, page 23.

b_1. Only part of the rays on transverse and tangential surfaces broad, the others narrower than the largest pores, therefore not appearing crowded; up to one-eighth inch wide with the grain on radial or tangential surfaces. Pores crowded in springwood, decreasing in size and number in the outer portion of the annual rings, thereby giving rise to a harder and darker band of summerwood. Wood heavy.

American Beech, page 23.

b. Largest rays about as wide as, or slightly wider than, the largest pores.

a_1. Heartwood deep reddish brown. Sapwood usually less than 1½ inches wide, Pores slightly decreasing in size from inner to outer portion of each annual ring, thereby defining the annual rings. Rays conspicuous on the radial surface, but not darker than the surrounding wood. Wood moderately heavy.

Black Cherry, page 25.

b_1. Heartwood light reddish brown. Sapwood usually several inches wide. Pores of uniform size throughout the annual ring. The rings defined by thin reddish-brown layer, usually conspicuous also on longitudinal surfaces. The rays conspicuous on the radial surface as reddish-brown flakes one thirty-second to one-sixteenth inch wide with the grain.

a_2. Wood heavy, difficult to cut across the grain with a knife. Only part of the rays broad, the others very fine, barely visible with a lens. Pith flecks rarely present.

Black Maple, page 25.
Sugar Maple, page 25.

b_2. Wood moderately heavy, fairly easy to cut across the grain with a knife. Practically all the rays broad, but not so broad as in sugar maple, therefore not so prominent but giving the appearance of being more numerous. Pith flecks common.

Red Maple, page 25.
Silver Maple, page 25.

c_1. Heartwood yellowish or brownish, with greenish tinge, sometimes purplish but never reddish brown. Wood moderately heavy.

Southern Magnolia, page 30.

c. Largest rays narrower than the largest pores.

a_1. Pores comparatively large under a lens, and barely visible without a lens under conditions of good light; visible without a lens on a smooth longitudinal surface as fine grooves.

a_2. Heartwood brown or reddish brown; without characteristic odor.

a_3. Wood heavy to very heavy.

Sweet Birch, page 27.
Yellow Birch, page 27.

b_3. Wood moderately heavy.

Alaska Birch, page 27.
Paper Birch, page 27.

b_2. Heartwood grayish white; with faint but characteristic odor when worked. Wood light to moderately light.

Cottonwood, page 31.

b_1. Pores very small, not visible without a lens.

a_2. Heartwood reddish brown, often figured with irregular darker streaks; sapwood white or pinkish. Wood moderately heavy; grain usually interlocked.

Sweetgum, page 29.

b_2. Heartwood yellowish or brownish, usually with greenish tinge, sometimes purplish, never reddish brown. Wood moderately light to moderately heavy. Grain usually straight.

Cucumbertree, page 30.
Yellowpoplar, page 29.

c_2. Heartwood light colored.

a_3. Heartwood creamy white or occasionally slightly reddish, not clearly defined from the sapwood. Larger rays conspicuous under a lens; 2 to 10 pore-widths apart. Rays often conspicuous on radial surfaces as flecks (sometimes reddish) up to three thirty-seconds inch wide with the grain. Wood light; has faint odor when worked. Grain usually straight.

BASSWOOD, page 30.

b_3. Heartwood light gray, clearly but not conspicuously defined from white sapwood. Rays not conspicuous under lens, all 1 to 3 pore-widths apart. Inconspicuous on radial surfaces. Wood light to moderately heavy; without characteristic odor. Grain usually interlocked.

WATER TUPELO, page 31.

SOFTWOODS

II. Wood without pores. The fibrous cells (tracheids) very small; practically uniform in size except in the summerwood, where they are narrower radially; arranged throughout in definite radial rows. Rays very fine.

A. Resin ducts present; visible without a lens on longitudinal surfaces as brownish lines. Occasionally pitch pockets, pitch streaks, and exudations of resin also present. Resinous, or pitchy, odor.

1. Individual resin ducts very distinct on cross sections under a lens, appearing as minute openings; numerous, but normally not in rows.

THE PINES.

a. Summerwood inconspicuous and only slightly harder than the springwood when cut across the grain. Heartwood light reddish or creamy brown. Wood light to moderately light.

EASTERN WHITE PINE, page 35.
WESTERN WHITE PINE, page 35.
SUGAR PINE, page 35.

b. Summerwood conspicuously darker and harder than the springwood, appearing as a glistening layer on transverse or longitudinal surfaces, although usually narrow. Wood moderately light to moderately heavy.

PONDEROSA PINE, page 37.
RED PINE, page 37.

2. Individual resin ducts indistinct on cross sections under a lens, appearing as whitish specks; not numerous, frequently in tangential rows of two or more.

a. Heartwood reddish or yellowish; with characteristic slightly resinous odor different from pine. Wood moderately light to moderately heavy.

DOUGLAS-FIR, page 37.

b. Heartwood moderately dark brown or reddish brown, much darker than sapwood; odorless. Wood moderately heavy.

WESTERN LARCH, page 39.

c. Heartwood pale reddish brown, slightly darker than sapwood; odorless. Wood moderately light.

SITKA SPRUCE, page 39.

d. Heartwood almost white, same color as sapwood; odorless. Wood moderately light.

RED SPRUCE, page 39.
WHITE SPRUCE, page 39.

B. Resin ducts, pitch pockets, pitch streaks, and exudations of resin normally absent.

1. Odor of dry wood distinctive.

a. Heartwood light canary yellow. Odor not spicy or aromatic, somewhat disagreeable. Wood moderately heavy.

ALASKA YELLOW-CEDAR, page 33.

b. Heartwood pale brown, not reddish.

a_1. Odor pungently spicy. Heartwood not much darker than sapwood. Wood moderately light.

PORT ORFORD WHITE-CEDAR, page 33.

b_1. Odor mildly aromatic, not pungent. Heartwood distinctly darker than sapwood. Wood very light.

NORTHERN WHITE-CEDAR, page 33.

c. Heartwood moderately light to dark brown or reddish brown.

a_1. Heartwood with bitter taste, odor resembling cedar shingles. Wood light.

a_2. Rays, as seen under a hand lens on freshly split radial surface, light brown, rarely containing amber-colored specks of resin. Springwood not firm. Sapwood usually less than 1 inch wide.
Western Redcedar, page 33.

b_2. Rays, as seen under a hand lens on freshly split radial surface, orange red with numerous fine amber-colored specks of resin. Springwood firm. Sapwood usually over 1½ inches wide.
California Incense-Cedar, page 33.

b_1. Heartwood without characteristic taste, odor somewhat rancid. Longitudinal surfaces often feel and appear waxy. Weight variable from moderately light to moderately heavy.
Baldcypress, page 41.

2. Odor of dry wood faint, not distinctive—practically odorless and tasteless. Wood light to moderately light.

a. Heartwood medium to dark reddish brown, sapwood white.
Redwood, page 42.

b. No distinction in color between heartwood and sapwood, both pale reddish brown.

a_1. Springwood white, summerwood brown with lavender tinge.
Pacific Silver Fir, page 42.
White Fir, page 42.

b_1. Springwood and summerwood pale reddish brown.
California Red Fir, page 42.
Noble Fir, page 42.
Western Hemlock, page 44.

2.2. GENERAL CHARACTERISTICS.

2.20. Specific Gravity and Unit Weights of Wood. The specific gravity or unit weight of a piece of wood based on its weight and volume when oven dry or at a known moisture content affords a good index of its strength when free from weakening defects. In any species pieces of low specific gravity are almost invariably low in strength properties for the species. Consequently specifications for aircraft lumber and requirements for important parts include minimum allowable values of specific gravity. Also, in order to avoid exceptionally heavy pieces upper limits of specific gravity are included for some species (sec. 2.414). Since both the weight and volume (below the fiber-saturation point) of a piece of wood change with changes in moisture content, it is necessary to specify conditions under which the weight and volume are to be measured.

For convenience specific gravity requirements for wood in aircraft are based on weight and volume when oven dry. Some of the current issues of AN specifications for aircraft woods give, in addition to the minimum values of specific gravity on this basis, equivalent values of weight per cubic foot (including moisture) at several values of moisture content in the range of 8 to 16 percent as alternatives.

Specification AN–W–4a describes three methods for the determination of specific gravity based on weight and volume when oven dry. These are designated respectively "Volumetric displacement," "Linear measurement," and "Empirical." The first two depend on obtaining the weight and volume of pieces of wood after they have been dried to zero moisture content. Obviously, they can be used only on samples and are not applicable to actual airplane parts. The "Empirical" method may be applied to actual parts, or to full-sized pieces of lumber and is readily usable for production control. It depends on determining the weight (in pounds) and the volume (in cubic inches), estimating the moisture content by moisture meter or otherwise, dividing weight by volume, and multiplying the result by a factor F which takes into account the units of weight and volume employed, the expected shrinkage from the current moisture content to zero, and the weight of moisture included in the piece. The result is a computed value of specific gravity based on weight and volume when oven dry. Values for F for a number of aircraft species and for different values of moisture content are given in a table included in the specification.

Table 2–4 gives average and minimum permissible values of unit weight for the oven-dry condition and for 15 percent moisture content together with values of the change in unit weight accompanying a change of 1 percent in moisture content.[1] The averages at 15 percent may be used directly to compute the average weights of wood parts at that moisture content and with the aid of values from columns 11 or 12 the average weight at some other moisture content may be computed. The tabulated minimum weights may be used to determine whether or not a piece of material is above the specified minimum weight. The following example illustrates this use:

A spruce spar 1⅟16 by 5½ inches by 17½ feet is found to weigh 17.35 pounds, and the moisture content indicated by an electric moisture meter is 11 percent. What is the specific gravity of the spar based on weight and volume when oven dry?

---

[1] The values in table 2-4, columns 4 and in 6 to 12, inclusive, were derived from the averages in columns 2 and 3 and the minimum given in column 5 by the steps indicated in the footnotes to the table. Values of minimum permissible weights per cubic foot at 15 percent moisture content in this table do not agree exactly with those in the several AN specifications for aircraft woods and computations made from this table may disagree slightly with those that may be made from table 1 of AN Specification AN–W–4a. In general, the discrepancies are not significant. They are due to slight differences in the assumptions on which the several sets of underlying computations are based.

TABLE 2-4.—*Average and minimum values of specific gravity and weight for various aircraft woods under different conditions of moisture and accompanying adjusting constants*

Species	Average specific gravity based on weight when oven dry and volume when green	Specific gravity and weight per cubic foot based on weight and volume when oven dry				Grams per cubic centimeter and pounds per cubic foot based on weight and volume at 15 percent moisture content				Constants [1] for adjusting values for each 1 percent change in moisture content	
		Average		Minimum permitted		Average		Minimum permitted			
		Specific gravity	Weight per cubic foot	Specific gravity [2]	Weight per cubic foot	Grams per cubic centimeter [3]	Weight per cubic foot [4]	Grams per cubic centimeter [5]	Weight per cubic foot [6]	For grams per cubic centimeter [3]	For pounds per cubic foot [7]
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Hardwoods (broadleaved species):			*Pounds*		*Pounds*		*Pounds*		*Pounds*		
Ash, black	0.451	0.531	33.1	0.48	30.0	0.553	34.5	0.502	31.3	0.00147	0.092
Ash, commercial white [8]	.535	.618	39.6	.56	34.9	.651	40.6	.593	37.0	.00220	.137
Basswood, American	.325	.398	24.8	.36	22.5	.405	25.3	.367	22.9	.00047	.029
Beech, American	.563	.671	41.9	.60	37.4	.694	43.3	.623	38.9	.00153	.095
Birch, Alaska	.488	.594	37.1	.53	33.1	.607	37.9	.543	33.9	.00087	.054
Birch, paper	.484	.600	37.4	.54	33.7	.607	37.9	.547	34.1	.00047	.029
Birch, sweet and yellow	.574	.688	42.9	.58	36.2	.709	44.2	.601	37.5	.00140	.087
Cherry, black	.471	.534	33.3	.48	30.0	.569	35.5	.515	32.1	.00233	.145
Cottonwood, eastern	.372	.433	27.0	.39	24.3	.454	28.3	.411	25.6	.00140	.087
Elm, American	.458	.554	34.6	.50	31.2	.568	35.4	.514	32.1	.00093	.058
Elm, rock	.574	.658	41.1	.60	37.4	.696	43.4	.638	39.8	.00253	.158
Hickory (true hickories) [9]	.641	.801	50.0	.71	44.3	.806	50.3	.715	44.6	.00033	.021
Khaya ("African mahogany")	.429	.467	29.1	.42	26.2	.510	31.8	.463	28.9	.00287	.179
Locust, black	.659	.708	44.2	64	39.9	.779	48.6	.711	44.4	.00473	.295
Magnolia, southern	.460	.530	33.1	.48	30.0	.559	34.9	.509	31.8	.00193	.120
Mahogany [10]	.459	.508	31.7	.46	28.7	.549	34.3	.501	31.3	.00273	.170
Maple, red	.486	.546	34.1	.46	28.7	.585	36.5	.499	31.1	.00260	.162
Maple, silver	.439	.506	31.6	.46	28.7	.534	33.3	.488	30.5	.00187	.117
Maple, sugar	.564	.676	42.2	.60	37.4	.697	43.5	.621	38.8	.00140	.087
Oak, commercial red [11]	.561	.676	42.2	.62	38.7	.695	43.4	.639	39.9	.00127	.079
Oak, commercial white [12]	.592	.719	44.9	.62	38.7	.736	45.9	.637	39.7	.00113	.071
Pecan	.601	.694	43.3	.62	38.7	.731	45.6	.657	41.0	.00247	.154
Sweetgum	.441	.530	33.1	.48	30.0	.546	34.1	.496	31.0	.00107	.067
Sycamore, American	.456	.539	33.6	.49	30.6	.560	34.9	.511	31.9	.00140	.087
Tupelo, water	.455	.524	32.7	.47	29.3	.553	34.5	.499	31.1	.00193	.120
Walnut, black	.513	.562	35.1	.52	32.4	.611	38.1	.569	35.5	.00327	.204
Yellowpoplar	.376	.427	26.6	.38	23 ·7	.454	28.3	.407	25.4	.00180	.112
Softwoods (coniferous species):											
Baldcypress	.425	.482	30.1	.43	26.8	.513	32.0	.461	28.8	.00207	.129
Douglas-fir (coast):											
Class N	.448	.512	31.9	.45	28.1	.543	33.9	.481	[13] 30.0	.00207	.129
Class L	.381	.432	27.0	[14] .38	23.7	.460	28.7	.408	[13] 25.5	.00187	.117
Fir, California red	.372	.421	26.3	.38	23.7	.449	28.0	.408	25.5	.00187	.117
Fir, noble	.351	.403	25.1	.36	22.5	.426	26.6	.383	23.9	.00153	.095
Fir, Pacific silver	.351	.415	25.9	.38	23.7	.431	26.9	.396	24.7	.00107	.067
Fir, white	.348	.397	24.8	.36	22.5	.421	26.3	.384	24.0	.00160	.100
Hemlock, western	.382	.443	27.6	.40	25.0	.466	29.1	.423	[13] 26.4	.00153	.095
Incense-cedar, California	.346	.365	22.8	.32	20.0	.406	25.3	.361	22.5	.00273	.170
Larch, western	.482	.587	36.6	.53	33.1	.600	37.4	.543	33.9	.00087	.054
Pine, eastern white	.344	.373	23.3	.34	21.2	.408	25.5	.375	23.4	.00233	.145
Pine, ponderosa	.379	.420	26.2	.38	23.7	.454	28.3	.414	25.8	.00227	.142
Pine, red	.440	.507	31.6	.46	28.7	.535	33.4	.488	30.5	.00187	.117

Pine, sugar	.348	.378	23.6	.34	21.2	.413	25.8	.375	23.4	.00233	.145
Pine, western white	.363	.418	26.1	.38	23.7	.441	27.5	.403	25.1	.00153	.095
Redcedar, western	.310	.342	21.3	.31	19.3	.370	23.1	.338	21.1	.00187	.117
Redwood	.380	.416	26.0	.38	23.7	.453	28.3	.417	26.0	.00247	.154
Sprue, red, white, and Sitka	.362	.407	25.4	.36	22.5	.436	27.2	.389	[13] 24.3	.00193	.120
White-cedar, northern	.293	.315	19.7	.29	18.1	.346	21.6	.321	20.0	.00207	.129
White-cedar, Port Orford	.399	.440	27.5	[14] .40	25.0	.477	29.8	.437	27.3	.00247	.154
Yellow-cedar, Alaska	.415	.465	29.0	.41	25.6	.499	31.1	.444	27.7	.00227	.142

---

[1] (Columns 11 and 12.) To adjust value to an oven-dry weight and volume basis or to any desired moisture content, add constant to value to be adjusted for each 1 percent increase in moisture below the fiber-saturation point; subtract constant from value to be adjusted for each 1 per cent decrease in moisture below the fiber-saturation point. These constants take shrinkage or swelling with moisture changes into consideration.

[2] Minimum permitted values are from ANC Handbook on Design of Wood Aircraft Structures Supplement No. 2, p. 11, table 2-1, February 1943.

[3] Values in column 7 are obtained by taking 1.15 times the quantity, column 3 minus five-eighths of the difference between column 3 and column 2, namely, column 7=1.15 [col. 3−⅝ (col. 3−col. 2)]; (col. 7−col. 3)÷15=col. 11.

[4] Values in this column are equal to values in column 7 times 62.4.

[5] Values in this column are equal to values in column 5 plus column 7 minus column 3.

[6] Values in this column are equal to values in column 9 times 62.4.

[7] Values in this column are rounded from the product of the values in column 11 and 62.4. These may be used for direct adjustment of pounds per cubic foot with differences in moisture content below the fiber-saturation point but will be only approximate for changes greater than 8 percent moisture.

[8] Includes white ash, green ash, and blue ash.

[9] Includes shellbark hickory, mockernut hickory, pignut hickory, and shagbark hickory.

[10] Includes material from Central America and Cuba.

[11] Includes white oak, bur oak, swamp chestnut oak, and post oak.

[12] Includes northern red oak, southern red oak, laurel oak, water oak, swamp red oak, willow oak, and black oak.

[13] This value does not agree exactly with the value given in current ANC specifications. The values in the specifications were prepared under slightly different basic assumptions and are as follows: Douglas-fir, class N, 29.7, class L, 25.1; western hemlock, 26.7; Sitka spruce, 23.9.

[14] Maximum value permitted, Douglas-fir, class L, 0.47; Port Orford white-cedar, 0.55.

The weight per cubic foot of the spar at 11 percent moisture content is:

$$\frac{17.35}{\frac{1.0625\times 5.5}{144}\times 17.5}=24.43 \text{ lb. per cu. ft.}$$

From column 12, table 2–4, the adjusting constant for 1 percent change of moisture content for spruce is 0.120. $0.120\times 11=1.32$. This value deducted from 24.43 (the weight per cubic foot at 11 percent moisture content) equals 23.11 pounds per cubic foot on an oven-dry basis. From table 2–5, 23.11 pounds per cubic foot equals a specific gravity of 0.371. This is the specific gravity of the spar based on its weight and volume when oven dry.

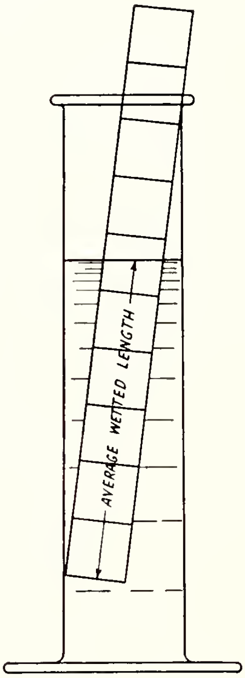

Figure 2–44.—Flotation method of determining specific gravity or unit weight. The operation may be expedited and the accuracy enhanced if the vessel is filled to overflowing and the water line marked on the specimen immediately after immersion.

Obviously also the data of table 2–4 can be used to establish schedules of minimum acceptable weights of parts having known volumes and moisture content. For example, the required weight of a spar of noble fir at 15 percent moisture content is 23.9 pounds per cubic foot (table 2–4, column 10). If a spar of this species has a volume of 0.710 cubic foot and weighs 16.85 pounds at 11 percent moisture content, what will be its weight per cubic foot at 15 percent moisture content?

Then the weight of the spar per cubic foot is $\frac{16.85}{0.710}$ or 23.73 lb.

From column 12, table 2–4, the constant for adjusting weight per cubic foot for noble fir is 0.095 per 1 percent moisture. To adjust the weight from 11 percent moisture content to 15 percent moisture content add (4×0.095) or 0.38 to 23.73 pounds per cubic foot. This equals 24.11 pounds per cubic foot at 15 percent moisture content. Therefore, this spar is acceptable since the minimum weight at 15 percent moisture content is 23.9 pounds per cubic foot.

The weight of the spar at any other moisture content may be obtained in a similar manner.

2.200. Flotation Method. A rapid method of determining the specific gravity or the unit weight consists of determining the proportion of a piece of wood with parallel sides and square ends that is submerged when it is floated in water with the longer dimension vertical or nearly so. That is illustrated by figure 2–44. The piece is carefully lowered into a container of water until it floats freely and then quickly removed so that water is not absorbed. Also the water level is marked on the sample before the wetted length is extended by capillary action. The average wetted length is measured, and this, divided by the total length, gives the specific gravity directly of oven-dry samples. With samples of known moisture content below the fiber-saturation point the values obtained by the flotation method may be converted to grams per cubic centimeter or weight per cubic foot at 15 percent moisture content, or to similar values on an oven-dry basis or to any desired moisture content for comparison by use of the constants from table 2–4, columns 11 and 12.

For example, if the wetted length of a specimen of sweet or yellow birch having a moisture content of 12 percent is six-tenths of its total length, the grams per cubic centimeter value is 0.60. To convert this to specific gravity on an oven-dry weight and volume basis, multiply 0.00140 (the adjusting constant for sweet and yellow birch from table 2–4) by 12 and subtract the product, 0.0168 from 0.60. This gives a specific gravity on the basis of weight and volume when oven-dry of 0.60 minus 0.017, or 0.583.

For the same sample to adjust the value of grams per cubic centimeter at 12 percent moisture content to grams per cubic centimeter at 15 percent moisture content, add 3×0.00140, or 0.0042, to 0.60 (gram per cubic centimeter at 12 percent moisture content) which equals 0.604 gram per cubic centimeter at 15 percent moisture.

With careful manipulation the flotation method has been found to give results accurate to about 0.01 gram per cubic centimeter. If a large proportion of the surface is end grain, as, for example, in a section 1 inch by 1 inch extending across the width of a board, speed is essential in making the immersion and marking the water line in order to avoid error from the absorption of water.

The use of the flotation method may be facilitated by estimating values directly from specimens marked in 10 equal units of length or by comparing them with a scale of equal length so marked. For determining the acceptability of material the required immersion depth may be marked on specimens before test.

2.201. Specific Gravity of Veneer. A method for determining the specific gravity or unit weight of wood in thin sheets, such as veneer or plywood, by means of a large graphic chart and spring balance is described in Forest Products Laboratory Mimeograph 1397 "A Rapid Method of Determining the Specific Gravity of Veneer."

2.202. Conversion Equivalents. Tables 2–5 and 2–6 list equivalents between pounds per cubic foot and grams per cubic centimeter or specific gravity that will be useful when conversion between these units is desired.

Means of arriving at grams per cubic centimeter or pounds per cubic foot by the use of different units of weight and measurement are given in table 2–7.

TABLE 2–5.—*Pounds per cubic foot and corresponding specific gravity values*

Pounds per cubic foot	Specific gravity	Pounds per cubic foot	Specific gravity	Pounds per cubic foot	Specific gravity
10	0. 160	28	0. 449	46	0. 737
11	. 176	29	. 465	47	. 753
12	. 192	30	. 481	48	. 769
13	. 208	31	. 497	49	. 785
14	. 224	32	. 513	50	. 801
15	. 240	33	. 529	51	. 817
16	. 256	34	. 545	52	. 833
17	. 272	35	. 561	53	. 849
18	. 288	36	. 577	54	. 865
19	. 304	37	. 593	55	. 881
20	. 321	38	. 609	56	. 897
21	. 337	39	. 625	57	. 913
22	. 353	40	. 641	58	. 929
23	. 369	41	. 657	59	. 946
24	. 385	42	. 673	60	. 962
25	. 401	43	. 689	61	. 978
26	. 417	44	. 705	62	. 994
27	. 433	45	. 721	62. 4	1. 000

TABLE 2–6.—*Specific gravity values and corresponding pounds per cubic foot*

Specific gravity	Pounds per cubic foot	Specific gravity	Pounds per cubic foot	Specific gravity	Pounds per cubic foot
0. 15	9. 4	0. 44	27. 5	0. 73	45. 6
. 16	10. 0	. 45	28. 1	. 74	46. 2
. 17	10. 6	. 46	28. 7	. 75	46. 8
. 18	11. 2	. 47	29. 3	. 76	47. 4
. 19	11. 9	. 48	30. 0	. 77	48. 0
. 20	12. 5	. 49	30. 6	. 78	48. 7
. 21	13. 1	. 50	31. 2	. 79	49. 3
. 22	13. 7	. 51	31. 8	. 80	49. 9
. 23	14. 4	. 52	32. 4	. 81	50. 5
. 24	15. 0	. 53	33. 1	. 82	51. 2
. 25	15. 6	. 54	33. 7	. 83	51. 8
. 26	16. 2	. 55	34. 3	. 84	52. 4
. 27	16. 8	. 56	34. 9	. 85	53. 0
. 28	17. 5	. 57	35. 6	. 86	53. 7
. 29	18. 1	. 58	36. 2	. 87	54. 3
. 30	18. 7	. 59	36. 8	. 88	54. 9
. 31	19. 3	. 60	37. 4	. 89	55. 5
. 32	20. 0	. 61	38. 1	. 90	56. 2
. 33	20. 6	. 62	38. 7	. 91	56. 8
. 34	21. 2	. 63	39. 3	. 92	57. 4
. 35	21. 8	. 64	39. 9	. 93	58. 0
. 36	22. 5	. 65	40. 6	. 94	58. 7
. 37	23. 1	. 66	41. 2	. 95	59. 3
. 38	23. 7	. 67	41. 8	. 96	59. 9
. 39	24. 3	. 68	42. 4	. 97	60. 5
. 40	25. 0	. 69	43. 1	. 98	61. 2
. 41	25. 6	. 70	43. 7	. 99	61. 8
. 42	26. 2	. 71	44. 3	1. 00	62. 4
. 43	26. 8	. 72	44. 9		

Table 2-7.—*Conversion factors for grams per cubic centimeter and pounds per cubic foot*

Given	To get—	
	Grams per cc.	*Pounds per cu. ft.*
	Multiply by	Multiply by
$\frac{\text{Weight in grams}}{\text{Volume in cubic centimeters}}$		62.4
$\frac{\text{Weight in pounds}}{\text{Volume in cubic feet}}$	0.016	
$\frac{\text{Weight in pounds}}{\text{Length in feet} \times \text{width in inches} \times \text{thickness in inches}}$	2.31	144
$\frac{\text{Weight in pounds}}{\text{Volume in cubic inches}}$	27.7	1728
$\frac{\text{Weight in ounces}}{\text{Volume in cubic inches}}$	1.73	108
$\frac{\text{Weight in grams}}{\text{Volume in cubic inches}}$	.061	3.81

2.203. Decimal Equivalents of Fractions of an Inch.

$\frac{1}{16}$ = 0.0625
$\frac{1}{8}$ = .125
$\frac{3}{16}$ = .1875
$\frac{1}{4}$ = .25
$\frac{5}{16}$ = .3125
$\frac{3}{8}$ = .375
$\frac{7}{16}$ = .4375
$\frac{1}{2}$ = .5
$\frac{9}{16}$ = .5625
$\frac{5}{8}$ = .625
$\frac{11}{16}$ = .6875
$\frac{3}{4}$ = .75
$\frac{13}{16}$ = .8125
$\frac{7}{8}$ = .875
$\frac{15}{16}$ = .9375

2.204. Weights of Wood Members. The weight per foot of length of a member having parallel sides may be computed as follows:

Example: To find the weight per 1 foot of length of a spar 1½ by 5⅝ inches in cross section having a moisture content of 12 percent.

1. The volume of 1 foot of length $=\frac{1.5\times5.625}{144}\times1=0.0586$ cu. ft.

2. From table 2-4 the average weight of spruce at 15 percent moisture content = 27.2 pounds per cubic foot.

3. Adjust pounds per cubic foot to the moisture content of the spar by use of the constant 0.120 from table 2-4 for each 1 percent change in moisture from 15 percent.

4. At 12 percent moisture content 1 cubic foot of the spar $=27.2-3\times0.120=26.84$, or 1 foot of length of the spar $=26.84\times0.0586=1.57$ pounds per foot of length.

2.21. Moisture Content.

2.210. Moisture Content of Green Lumber. In living trees, sapwood generally contains more water than heartwood. This is particularly true of the conifers, in the sapwood of which there is often considerably more water than in the heartwood. On the other hand, in many of the hardwoods the moisture content of heartwood and sapwood is more uniform—a condition which also applies to some of the softwoods.

Both sapwood and heartwood frequently contain more moisture at the base of the tree than higher up, but whether the upper part or butt of a tree contains more moisture per average unit volume for the entire cross section depends upon the species and conditions under which the tree grew. Trees with much more moisture in the sapwood may contain more water in proportion to their volume in the top logs because these generally contain a larger proportion of sapwood. On the other hand, trees in which the moisture distribution is more nearly uniform as a rule contain more water per unit volume or weight in the butt logs. Green butt logs of sugar pine, western larch, redwood, and western redcedar often sink in water, although the upper logs float.

It is a common belief that trees contain more moisture during the growing season, when the sap is said to be "up," than in the fall and winter when the sap is said to be "down." This belief has no foundation in fact. Tests made in the United States and Canada show that trees cut in the winter contain fully as much water as trees cut in the summer. Tests made in the tropics indicate as much or more moisture in trees before the rainy season than immediately after the rainy season.

The sapwood of living trees often contains more than 100 percent of moisture, and trees have been found in which the moisture content was over 300 percent of the dry weight. In such cases the cell walls are fully saturated, and the cell cavities are almost filled with water. In the heartwood of some green conifers the moisture content is as low as 30 percent.

There is a maximum amount of moisture which wood of any specific gravity can hold. For example, if a piece of wood could have a specific gravity of 1.5 (actually such wood does not exist) it would contain no air space and would be all wood substance so that there could be no room for moisture; a piece of wood with a specific gravity (based on oven-dry weight and green volume) of 0.40 could hold a maximum of 185 percent moisture, based on the dry weight of the wood.

The moisture content of seasoned wood is dependent upon the humidity and temperature of the surrounding air as discussed under "Seasoning and Storage of Lumber" (sec. 5.0).

2.211. Moisture Content Determination. Two methods of making moisture content determinations for wood are recognized: (1) by determination based upon the drying of a sample in an oven and (2) by means of electric moisture meters. They are not interchangeable, but they do complement one another, since each has a distinct field of usefulness not covered by the other.

An accurate determination of the moisture content of a test section of wood can be made by the oven-dry method, regardless of original moisture content, moisture distribution, size, species, density, or temperature of the stock being tested. On the other hand, it means cutting into and causing waste of a part of the original board or plank and 24 hours or more for drying before the moisture content can be determined. Since the moisture content will vary between pieces in a given lot or shipment, a number of tests by either method must be made to obtain an average. Such an average can be in error to whatever extent the tests made did not fully represent the total lot. Intelligent selection of test pieces and a suitable number of samples will minimize such error.

2.2110. Oven-dry Method. The moisture content of wood by the oven-dry method is determined as follows:

1. Select a representative sample of the material.
2. Immediately after sawing, remove all loose splinters and weigh the sample.
3. Put sample in an oven maintained at a temperature of 212° to 221° F. (100° to 105° C.) and dry until constant weight is attained.
4. Reweigh the sample to obtain the oven-dry weight.
5. Divide the loss in weight by the oven-dry weight and multiply the result by 100 to get the percentage of moisture in the original sample. Thus,

$$\text{Percentage moisture} = \frac{(W-D)}{D}100,$$

where

W=original weight as found under 2 above,

D=oven-dry weight as found under 4 above.

First Step: If possible, the sample should be taken at least 2 feet from one end of the piece. Wood gives off or takes on moisture more rapidly from the end grain than from side grain; as a result, there may be considerable difference between the moisture content at the end and elsewhere in a stick. For this reason, a sample from within about a foot of the end of a long board may not be representative.

Short pieces of wood dry out much more rapidly than longer ones. In order to reduce the time required for drying, therefore, the length of the sample in the direction of the grain should usually be about 1 inch. With material 1 square inch or less in cross-sectional area, however, a sample more than 1 inch long is generally desirable, and the length in this case may be chosen so as to give the sample a volume of 2 or more cubic inches. The other dimensions may be equal to the cross section of the board from which the sample is taken.

Second Step: It is important that the weight be taken immediately after the sample is cut, for the material is subject to moisture changes on exposure to the air. The degree and rapidity of changes are dependent on the moisture content of the piece and the air conditions to which it is exposed.

In order to insure good results, the weights should be correct to within at least one-half of 1 percent.

The metric system of weights is very convenient in making moisture determinations.

The kind of scales to be used and the size of smallest graduation necessary to insure the specified accuracy will depend on the weight, and consequently the size, of the sample and kind of wood. Small spring postal scales reading to one-half ounce are not suitable for accurate weighing of small moisture samples.

Third Step: When placed in the oven for drying, the samples shoud be open-piled to allow free access of air to each piece. The oven should have some ventilation, thus allowing the evaporated moisture to escape. A thermometer should be provided by which the temperature can be ascertained at any time. Excessive temperatures or excessive periods in the drying oven will cause distillation of the wood, and erroneous results will be obtained. Ordinarily, in the case of low-density woods, 12 hours' oven drying is sufficient, while high-density woods may require 48 hours' oven drying.

Fourth Step: As in the case of the first weight taken, it is essential that the sample be weighed immediately after being removed from the oven.

Fifth Step: A typical example of the computation necessary for determining the percentage of moisture is:

A 2- by 2- by 1-inch sample of air-dry Sitka spruce weighed 30.8 grams. The sample after oven-drying weighed 27.5 grams. Find the moisture content of the sample.

$$\text{Percentage moisture} = \frac{(30.8-27.5)}{27.5}\times 100 = \frac{330}{27.5} = 12.$$

2.2111. Electric Moisture Meters. Electric moisture meters give an instantaneous moisture content reading, based on the effect of the moisture on the electrical resistance or capacity of the piece. The values are affected by a number of factors, such as density, species, temperature, moisture distribution, and thickness of material. The presence of glue or paint may affect the accuracy. Many moisture meters are limited to readings covering a moisture-content range between 7 and 25 percent.

Moisture meters will not satisfactorily serve in place of kiln samples used in dry kilns for guidance of kiln operation. However, the work of an inspector charged with the control of moisture in wood may be greatly facilitated and the value of his judgment enhanced by the use of electrical moisture-indicating instruments. These instruments give instantaneous readings and are sufficiently accurate for the control of moisture content of materials being processed, or purchased under moisture content specifications. Since such materials are generally of a single species, the necessary corrections can be made for species and for temperatures, approximately between 30° and 100° F., thus greatly simplifying the procedure. Occasional check readings should be made against stock of the same shipments and species where the moisture content has been determined by the oven-dry method. Such check readings should preferably be made before cutting on the same section used to determine moisture content by the oven-dry method. It is not to be expected that the moisture-meter readings will agree absolutely in each case with the oven-dry determination. When differences occur, the oven-drying tests should be resorted to and should take precedence over the meter readings.

The following example indicates how a moisture meter might be used: A given lot of airplane spruce is to be taken from the storage piles into the cut-up room. The specification limits the moisture content to a range of 1½ percent above and below the average and states the average acceptable. Oven-dry tests are made of a number of pieces, and moisture-meter tests are made on the same pieces. The first test may indicate a moisture content of 9 percent, and the meter may indicate 10 percent after corrections for species and density have been made. It may be assumed that all other material of the same species, density, and moisture content would give the same reading on the meter. The inspector may correct for the difference between the two methods of moisture determination and continue with the meter method to check as many pieces as are necessary, even all pieces under some conditions, discarding all material that did not fall within the acceptable range. All material not acceptable could be returned to the storage shed for further conditioning. Moisture meters would be valuable also in checking the moisture content of air-dry stock before shipment from the mill.

The electrical-resistance type is generally supplied with a range of measurement of 7 to 25 percent, although some meters have special scales extending to about 60 percent. Measurements made within the higher range are not, however, so accurate as those made at from 7 to 25 percent. Fortunately, most measurements needed are between 7 and 25 percent, and the higher range is used only in special cases.

Measurements of electrical resistance with a portable meter become very difficult to make at moisture content values below 7 percent because of the high electrical resistance of dry wood. The electrical resistance of wood varies with species and temperatures, and corrections should be applied for these variables.

Instruments which measure the electrical capacity of wood may also be used for determining variations in moisture content. In this case, a high frequency field is created by the instrument adjacent to the electrode. Materials introduced into this electrical field absorb energy and affect the flow of current in the circuit. This change is shown by a meter which may contain a calibration for a single species, or an arbitrary scale may be used which can be converted into moisture content readings from tables supplied by the manufacturer. Variations in the density of the wood affect the accuracy of the capacity-type instrument, so that the instrument should not be used indiscriminately on species of unknown calibration.

The following conditions should be observed in making moisture content tests electrically:

(1) Follow the written instructions of the manufacturer of the moisture meter.

(2) Apply corrections for species, temperature, or density when necessary.

(3) Measurements should be made at several points on the faces of the boards.

(4) No measurements should be made on the end of lumber.

(5) Moisture content values should not be assumed when calibrations have not been made.

(6) Drive needle points full depth and with the current flow parallel to the grain.

(7) Plate electrodes, such as on capacitance type meters, should not be used on rough lumber.

(8) Measurements should not be made on lumber which has been subjected to surface wetting, such as rain or fog.

(9) Measurements above 100° F. or below 30° F. are not recommended because of lack of satisfactory temperature-correction data.

(10) If the needle points cause splitting of veneers, disregard the readings.

(11) Moisture content measurements with needle electrodes on plywood should be regarded as approximate, since glue lines containing electrolytes are likely to show moisture-content values that are too high.

(12) The use of moisture meters on material thicker than 1 inch should be permitted if contact points are driven to a depth equal to one-fifth of the thickness of the material.

(13) If a moisture meter does not function properly, it should be returned to the manufacturer for recalibration.

2.22. Rings per Inch. Rings per inch, or its inverse, the width or thickness of growth rings, is a measure of the rate of diameter growth of the tree. Rings per inch is not in any species a definite criterion of strength. Specifications for aircraft woods include requirements for a minimum number of rings per inch in order to decrease the probability of low strength values in coniferous species and the likelihood of objectionable warping in either hardwoods or softwoods and to promote uniformity in the material (sec. 2.414). Material below the required minimum specific gravity and having low strength values is more likely to be found among pieces of coniferous species with a number of rings per inch below the specified minimum or, regardless of species, among pieces with an exceptionally large number of rings per inch. Rejection of material on the basis of the number of rings per inch is somewhat arbitrary, because it does not always reflect the strength of the piece.

Rings per inch should be measured at the end of a piece of wood and in a radial direction. Measurement or count on a longitudinal surface is accurate only when the surface is truly radial or edge grained.

2.23. Amount of Summerwood. The inspector should not use the amount of summerwood as a sole criterion for acceptance or rejection of airplane material.

In some species the proportion of summerwood is indicative of the specific gravity and therefore of the strength. This is particularly true of southern yellow pine and Douglas-fir. After some practice the inspector will be able, through observation of the proportion of summerwood, to form a fairly good idea of whether any particular piece is considerably below, considerably above, or near the required specific gravity. The proportion of summerwood, however, is not a sufficiently accurate indicator of strength to permit its use as the sole criterion for the acceptance or rejection of airplane material. For example, a piece of wood may contain a large percentage of summerwood and show a good weight but yet may be brash because of such defects as compression wood, compression failures, and decay. Also summerwood itself may be of variable density, though such differences are not easily recognized.

2.24. Shrinkage of Wood. Wood, like many other materials, shrinks as it loses moisture and swells as it absorbs moisture.

While wood in its green condition as it comes from the tree may contain water ranging in quantity from 30 to 250 percent, based on the weight of the oven-dry wood, the removal of only the last 25 or 30 percent of this moisture content has the effect of shrinking the wood on drying out; and since wood in service is never totally dry, the possible shrinkage effect falls within a relatively narrow range. Water is held in the wood in two distinct ways—imbibed water in the walls of the wood cells and free water in the cell cavities. When wood begins to dry, the free water leaves first, followed by the imbibed water. The fiber-saturation point is that condition in which all the free water has been removed but all the imbibed water remains; for most woods this point is between 25 and 30 percent moisture content.

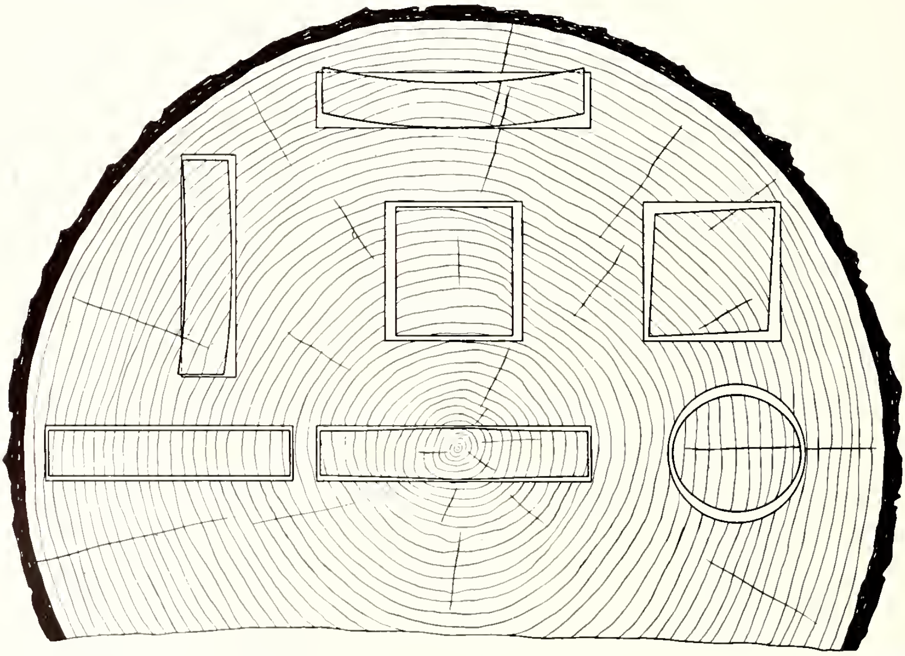

FIGURE 2-45.—Effects of radial and tangential shrinkage on the shape of various sections in drying from the green condition.

Wood changes size with moisture content only below the fiber-saturation point. Since, in seasoning green wood, the surface dries more rapidly than the interior and reaches the fiber-saturation point first, shrinkage may start while the average moisture content is considerably above the fiber saturation point. Wood skrinks most in the direction of the annual growth rings (tangentially), about one-half to two-thirds as much across these rings (radially), and very little, as a rule, along the grain (longitudinally). The joint effects of radial and tangential shrinkage on the shape of various sections in drying from the green condition are illustrated in figure 2-45. When a board is excessively cross-grained the lengthwise shrinkage is a combination of crosswise and longitudinal shrinkage, resulting in a greater shortening than would occur in a straight-grained piece. Shrinkage is usually expressed as a percentage of the green dimensions, which represent the natural size of the piece. Table 2-8 gives the range in shrinkage in different directions for most of the commercially important native species.

Table 2-8.—*Range in average shrinkage of a number of native species of wood*

Direction of shrinkage	From green to oven-dry condition	From green to air-dry condition (12- to 15-percent moisture content)
	Percent of green size	*Percent of green size*
Tangential	4. 3–14. 0	2. 1 – 7. 0
Radial	2. 0– 8. 5	1. 0 – 4. 2
Longitudinal	. 1– . 2	. 05– . 10
Volumetric	7. 0–21. 0	3. 5 –10. 5

Shrinkage in drying is proportional to the moisture lost below the fiber-saturation point. Approximately one-half the total shrinkage possible has occurred in wood seasoned to an air-dry condition (12- to 15-percent moisture content) and about three-fourths in lumber kiln dried to a moisture content of about 7 percent. Hence, if wood is properly seasoned, manufactured, and installed at a moisture content in accord with its service conditions, there is every prospect of satisfactory performance without serious changes in size or distortion of section.

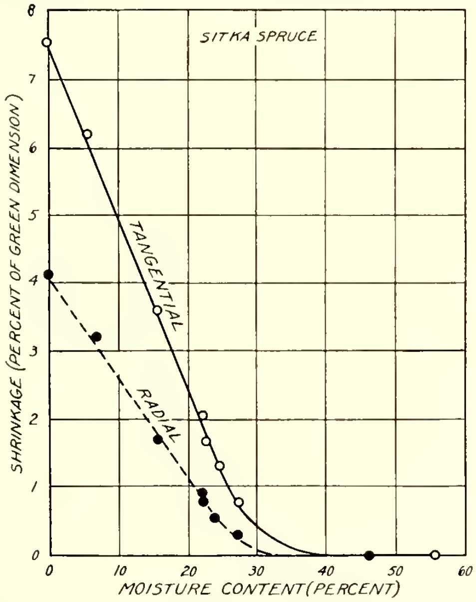

Figure 2-46.—Moisture content-shrinkage relation in Sitka spruce lumber.

In general the heavier species of wood shrink more across the grain than the lighter ones. Heavier pieces also shrink more than lighter pieces of the same species. When shrinkage is more of a factor than hardness or strength, a lightweight species should be chosen. When both hardness or strength and low shrinkage are very important, then an exceptional species, such as black locust, should be chosen.

The average tangential, radial, and volumetric shrinkages for individual species dried to an air-dry, kiln-dry, or oven-dry condition are given in table 2-9.

TABLE 2-9—*Shrinkage values for commercially important aircraft woods*

Species	Shrinkage (percent of dimension when green) from green to—								
	Air dried to 12 to 15 percent moisture [1] (estimated values)			Kiln dried to 6 to 7 percent moisture [2] (estimated values)			Oven dried to 0 percent moisture (test values)		
	Radial	Tangential	Volumetric	Radial	Tangential	Volumetric	Radial	Tangential	Volumetric
Hardwoods (Broad-leaved species)	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Ash, black	2.5	3.9	7.6	3.8	5.8	11.4	5.0	7.8	15.2
Ash, commercial white [3]	2.3	3.8	6.4	3.4	5.6	9.6	4.6	7.5	12.8
Basswood, American	3.3	4.6	7.9	5.0	7.0	11.8	6.6	9.3	15.8
Beech, American	2.6	5.5	8.2	3.8	8.2	12.2	5.1	11.0	16.3
Birch, Alaska	3.2	5.0	8.4	4.9	7.4	12.5	6.5	9.9	16.7
Birch paper	3.2	4.3	8.1	4.7	6.4	12.2	6.3	8.6	16.2
Birch [4]	3.4	4.4	8.2	5.2	6.7	12.2	6.9	8.9	16.3
Cherry, black	1.8	3.6	5.8	2.8	5.3	8.6	3.7	7.1	11.5
Cottonwood, eastern	2.0	4.6	7.0	2.9	6.9	10.6	3.9	9.2	14.1
Elm, American	2.1	4.8	7.3	3.2	7.1	11.0	4.2	9.5	14.6
Elm, rock	2.4	4.0	7.0	3.6	6.1	10.6	4.8	8.1	14.1
Hickory (true hickories) [5]	3.6	5.7	9.0	5.5	8.6	13.4	7.3	11.4	17.9
Khaya ("African mahogany")	2.0	2.9	4.4	3.1	4.4	6.6	4.1	5.8	8.8
Locust, black	2.2	3.4	4.9	3.3	5.2	7.4	4.4	6.9	9.8
Magnolia, southern	2.7	3.3	6.2	4.0	5.0	9.2	5.4	6.6	12.3
Mahogany	1.7	2.4	3.8	2.6	3.6	5.8	3.5	4.8	7.7
Maple, red	2.0	4.1	6.6	3.0	6.2	9.8	4.0	8.2	13.1
Maple, silver	1.5	3.6	6.0	2.2	5.4	9.0	3.0	7.2	12.0
Maple, sugar	2.4	4.8	7.4	3.7	7.1	11.2	4.9	9.5	14.9
Oak, commercial red [6]	2.2	4.5	7.4	3.2	6.8	11.1	4.3	9.0	14.8
Oak, commercial white [7]	2.7	4.6	8.0	4.0	7.0	12.0	5.4	9.3	16.0
Pecan	2.4	4.4	6.8	3.7	6.7	10.2	4.9	8.9	13.6
Sweetgum	2.6	5.0	7.5	3.9	7.4	11.2	5.2	9.9	15.0
Sycamore, American	2.6	3.8	7.1	3.8	5.7	10.6	5.1	7.6	14.2
Tupelo, water	2.1	3.8	6.2	3.2	5.7	9.4	4.2	7.6	12.5
Walnut, black	2.9	4.4	6.3	4.3	6.6	9.5	5.8	8.8	13.0
Yellowpoplar	2.0	3.6	6.2	3.0	5.3	9.2	4.0	7.1	12.3
Softwoods (Conifers)									
Baldcypress	1.9	3.1	5.2	2.8	4.6	7.9	3.8	6.2	10.5
Douglas-fir	2.5	3.9	5.9	3.8	5.8	8.8	5.0	7.8	11.8

Fir, California red	1. 9	3. 4	5. 9	2. 8	5. 2	8. 8	3. 8	6. 9	11. 8
Fir, noble	2. 2	4. 1	6. 2	3. 4	6. 2	9. 4	4. 5	8. 3	12. 5
Fir, Pacific silver	2. 2	5. 0	7. 0	3. 4	7. 5	10. 6	4. 5	10. 0	14. 1
Fir, white	1. 6	3. 5	4. 7	2. 4	5. 2	7. 0	3. 2	7. 0	9. 4
Hemlock, western	2. 2	4. 0	6. 0	3. 2	5. 9	8. 9	4. 3	7. 9	11. 9
Incense-cedar, California	1. 6	2. 6	3. 8	2. 5	3. 9	5. 7	3. 3	5. 2	7. 6
Larch, western	2. 1	4. 0	6. 6	3. 2	6. 1	9. 9	4. 2	8. 1	13. 2
Pine, eastern white	1. 2	3. 0	4. 1	1. 7	4. 5	6. 2	2. 3	6. 0	8. 2
Pine, ponderosa	2. 0	3. 2	4. 8	2. 9	4. 7	7. 2	3. 9	6. 3	9. 6
Pine, red	2. 3	3. 6	5. 8	3. 4	5. 4	8. 6	4. 6	7. 2	11. 5
Pine, sugar	1. 4	2. 8	4. 0	2. 2	4. 2	5. 9	2. 9	5. 6	7. 9
Pine, western white	2. 0	3. 7	5. 9	3. 1	5. 6	8. 8	4. 1	7. 4	11. 8
Redcedar, western	1. 2	2. 5	3. 8	1. 8	3. 8	5. 8	2. 4	5. 0	7. 7
Redwood	1. 3	2. 2	3. 4	2. 0	3. 3	5. 1	2. 6	4. 4	6. 8
Spruce [8]	2. 2	3. 9	6. 2	3. 2	5. 8	9. 2	4. 3	7. 8	12. 3
White-cedar, northern	1. 0	2. 4	3. 5	1. 6	3. 5	5. 2	2. 1	4. 7	7. 0
White-cedar, Port Orford	2. 3	3. 4	5. 0	3. 4	5. 2	7. 6	4. 6	6. 9	10. 1
Yellow-Cedar, Alaska	1. 4	3. 0	4. 6	2. 1	4. 5	6. 9	2. 8	6. 0	9. 2

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[1] These shrinkage values have been taken as one-half the shrinkage to the oven-dry condition as given in the last 3 columns of this table.

[2] These shrinkage values have been taken as three-fourths the shrinkage to the oven-dry condition as given in the last 3 columns of this table.

[3] Average of Biltmore white ash, blue ash, green ash, and white ash.

[4] Average of sweet birch and yellow birch.

[5] Average mockernut hickory, pignut hickory, shagbark hickory, and shellbark hickory.

[6] Average of black oak, eastern red oak, laurel oak, northern red oak, pin oak, scarlet oak, southern red oak, swamp red oak, water oak, and willow oak.

[7] Average of bur oak, chestnut oak, post oak, swamp chestnut oak, swamp white oak, and white oak.

[8] Average of red spruce, Sitka spruce, and white spruce.

Theoretically the normal moisture-content-shrinkage relation may be considered a direct one, from zero shrinkage at the fiber-saturation point to maximum shrinkage at zero moisture content. Actually, however, some shrinkage takes place before the average moisture content reaches the fiber-saturation point and the relationship in lumber of commercial size is somewhat similar to the curves in figure 2–46. For practical use, a straight-line relation may be assumed without appreciable error. The curves represent average values, and the shrinkage of an individual board may, of course, be above or below the amount indicated.

Changes in moisture content in seasoned wood, such as those caused by seasonal variation in relative humidity, produce changes in dimension proportional to the moisture-content changes. For example, assume that a piece of flat-sawed Sitka spruce board at 12 percent moisture content loses 5 percent of moisture. The shrinkage curve (marked "tangential") indicates that from the green condition to 7-percent moisture content the shrinkage in width would be, approximately, 5¾ percent; and to 12-percent moisture content, would be 4½ percent. The difference of 1¼ percent indicates the shrinkage in width of the board because of the 5-percent loss in moisture. These curves represent average values, and the shrinkage of an individual board may be below or above the indicated amount.

2.240. Effects of Change of Moisture Content on Curved Wood Members. Changes in moisture content with accompanying shrinkage or swelling, cause curved wood members (*a*) to increase or decrease in curvature if they are free to do so, or (*b*) to be subjected to internal stress if they are so held that the curvature cannot change. These phenomena are perhaps most readily understood by a consideration of what happens when moisture changes take place in a continuous circular ring formed by laminating. When moisture is lost the radial dimension, being across the grain, tends to decrease, whereas the inner and outer circumferences, being in the direction of the grain, have only an extremely small tendency to shrink. Consequently, the difference between the two circumferences remains too great for the decreased radial dimension. The result is a tension stress in the radial direction (across the grain of the wood), which tends to shorten the outer circumference, causing compressive stress along it, and at the same time tends to lengthen the inner circumference, causing tension stress. Conversely, increase in moisture content results in radial swelling, which causes radial compression; tension, or stretching, along the outer circumference; and compression along the inner circumference.

If the radial shrinkage or swelling is uniform around the circular ring, the stresses mentioned above will also be uniform around it and there will be no tendency for the shape to change. A ring that is other than circular or that varies in radial thickness may be expected to change shape.

With any type of curved member, other than a continuous ring formed by two concentric circles and in which the grain runs circumferentially, a change in moisture content will tend to cause a change of shape.

Loss of moisture and the accompanying shrinkage tends to make the usual curved piece more sharply curved and to increase the angle between the ends of the piece. Swelling has the opposite effect (fig. 2–47). In either case, the percentage change of angle in members that are not restrained is approximately the same as the percentage change in the radial dimension of the piece. Thus, if a curved member has a central angle of 100°, radial shrinkage of 1 percent will change the angle to 101° and swelling of 10 percent will change it to 99°.

These effects of shrinkage account for the common observations of the change of shape of curved wood members. Ordinarily, the changes that will occur cannot be accurately predicted, and it is consequently necessary either to make such pieces oversize and provide for machining at the time of assembly into a structure or to depend on springing the member into place.

Since shrinkage and swelling are least in the direction of the width of an edge-grained face, laminations of a curved laminated member should be flat-grained on their curved faces to make the member edge-grained on its noncurved faces, so that shrinkage and swelling in the direction of the radius of the curve, and the resultant stresses, will be minimized.

Thus solid stock which has been bent sufficiently to upset the fibers considerably on the concave side has a stronger tendency to straighten on absorbing moisture than laminated stock of the same total radial thickness because the upset fibers tend to straighten out lengthwise on absorption of moisture.

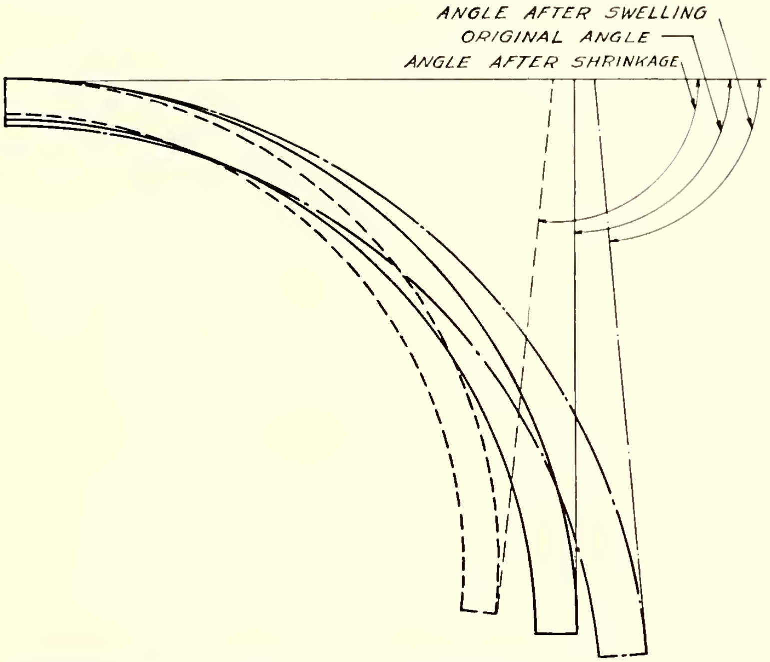

FIGURE 2-47.—Changes in curved wood member caused by shrinkage and swelling. Not drawn to scale.

2.3. DEFECTS AND BLEMISHES.

2.30. General. A defect is any irregularity occurring in wood that may lower its strength. A blemish is anything, not necessarily a defect, marring the appearance of the wood.

The following is a discussion of the nature and occurrence of defects and blemishes in aircraft lumber. Some of the defects here described are common, whereas others seldom occur in aircraft lumber or occur only in one or two species, and are recorded here mainly to afford reference in the event they are encountered by inspectors. The extent to which defects and blemishes are permissible in aircraft parts is given in section 2.4.

The frequency with which the more important defects and blemishes occur in nine softwoods that are in current or prospective use for aircraft is shown in table 2–10, which is based on a study of commercial lumber made at a number of representative mills. These data apply to the quality of lumber from which aircraft stock would necessarily be obtained, but most of this quality would fall short of aircraft specifications because of excessive cross grain or other defects. Defects would necessarily be relatively small in lumber grades of C and better, but, even so, some would be too large to meet aircraft specifications.

TABLE 2–10.—*Frequency of defects in present and prospective aircraft softwoods*

[Based on lumber of C and Better quality except as noted]

Species	Percent of pieces in which the following defects occurred:									
	Pitch pockets	Pitch streaks	Pitch	Knots	Worm holes	Bark pockets	Dark streak	Season checks	Stain	
									Blue	Brown
Sitka spruce	14	24	------	17	------	26	------	------	------	------
Douglas-fir (coast type)	33	28	7	8	------	2	------	4	1	2
Western hemlock	------	------	------	6	10	------	76	10	2	------
White fir [1]	------	------	------	66	4	------	27	19	5	------
Western larch	10	1	5	35	1	2	------	39	------	------
Sugar pine	8	8	10	15	------	3	------	3	4	5
Western white pine	6	6	27	45	1	1	------	20	9	1
Ponderosa pine	10	6	7	24	1	6	------	14	5	4
Redwood [2]	1	63	------	12	1	5	------	5	2	21

[1] Average for D and Better Inland Empire white fir and C and Better California white fir.

[2] Average for A Finish and B Finish; no C or D Finish made.

2.301. Knots. A knot is the base of a limb embedded in the tree trunk. Normally a knot starts at the pith and increases in diameter from the pith outward as

FIGURE 2–48.—Intergrown round knots in yellow pine.

long as the limb is alive. Occasionally, knots start at some distance from the pith as a result of the development of adventitious shoots.

As long as a limb remains alive, its fibers interlace with those of the tree trunk, producing an intergrown knot (fig. 2–48). Many of the lower limbs die, however, after a longer or shorter time as a result of shading, or other causes, but they may not break off for many years thereafter. After the death of a limb, the wood formed in the tree trunk makes no further connection with it but grows around it, producing an encased knot, which may be either loose, so that it will drop out, or tight, so that it is held in position when the trunk is sawed into lumber (fig. 2–49). When lumber

FIGURE 2–49.—Above: An encased knot (hemlock). Below: A spike knot, intergrown for most of its length (yellow pine).

dries, the knots shrink more than the surrounding wood, thereby becoming checked or loosened.

Eventually, the dead limb breaks off, the stub heals over, and the distortion of grain in successive growth layers becomes less and less with increasing diameter of the trunk, until finally clear wood with normal grain is produced in the area covering the knot.

A knot cut through transversely is known as a round knot, one cut through obliquely is known as an oval knot, and one cut through lengthwise is known as a spike knot (figs. 2–48 and 2–49). A sound, tight knot is solid across its face, fully as hard as the surrounding wood, shows no signs of decay, and is so fixed by growth or position that it will firmly retain its place in the piece. Only knots of this character are permitted in airplane stock. In the sizes allowed in aircraft stock, intergrown knots are necessarily tight and encased knots may be tight.

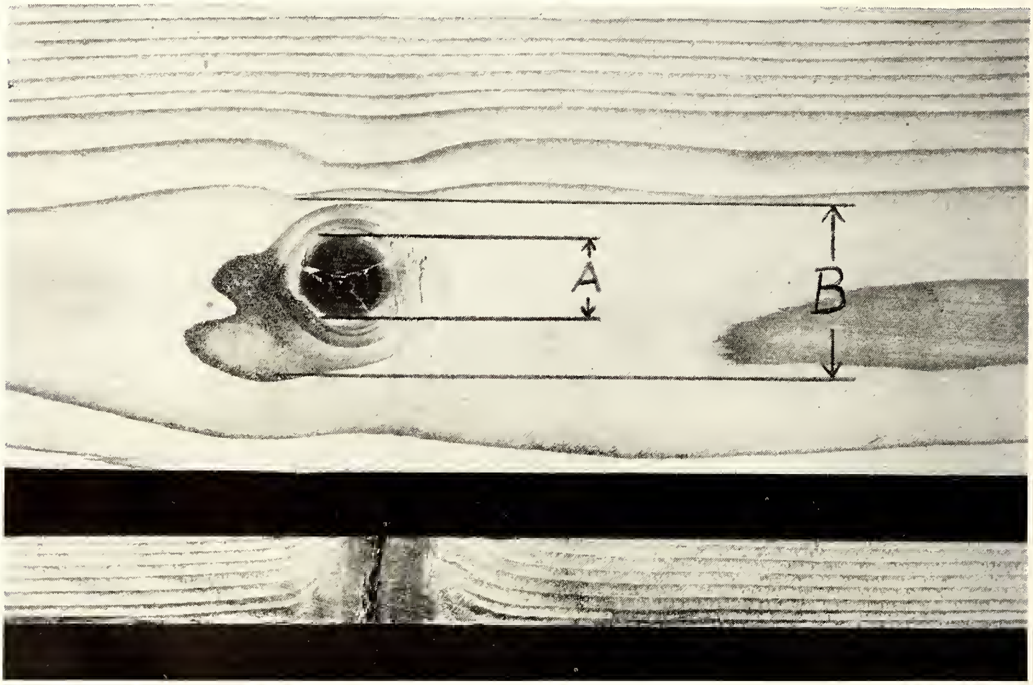

FIGURE 2–50.—Method of measuring a knot. Only the actual diameter, A, is measured. Bottom, a board with a knot shown in cross section.

Knots are objectionable on account of the distortion and, in encased knots, the discontinuity of the grain which they produce, thereby weakening the wood, causing irregular shrinkage, and making the machining more difficult; when loose they are likely to drop out; in resinous species pitch often exudes more freely from knots than from the clear wood; and in all woods knots are considered as marring the appearance of the lumber unless painted.

In measuring a knot, a question frequently arises as to whether only the knot itself or the more or less distorted grain immediately surrounding it should be included in the measurement. This distinction is plainly shown in figure 2–50. The knot proper, A, measured ⅜ inch, as compared with ¾ inch for the total area, B, which included a surrounding zone where the grain met the surface at an angle of about 45°. The method of measurement, therefore, would often determine the acceptability of the piece. The correct method is to measure only the knot proper,

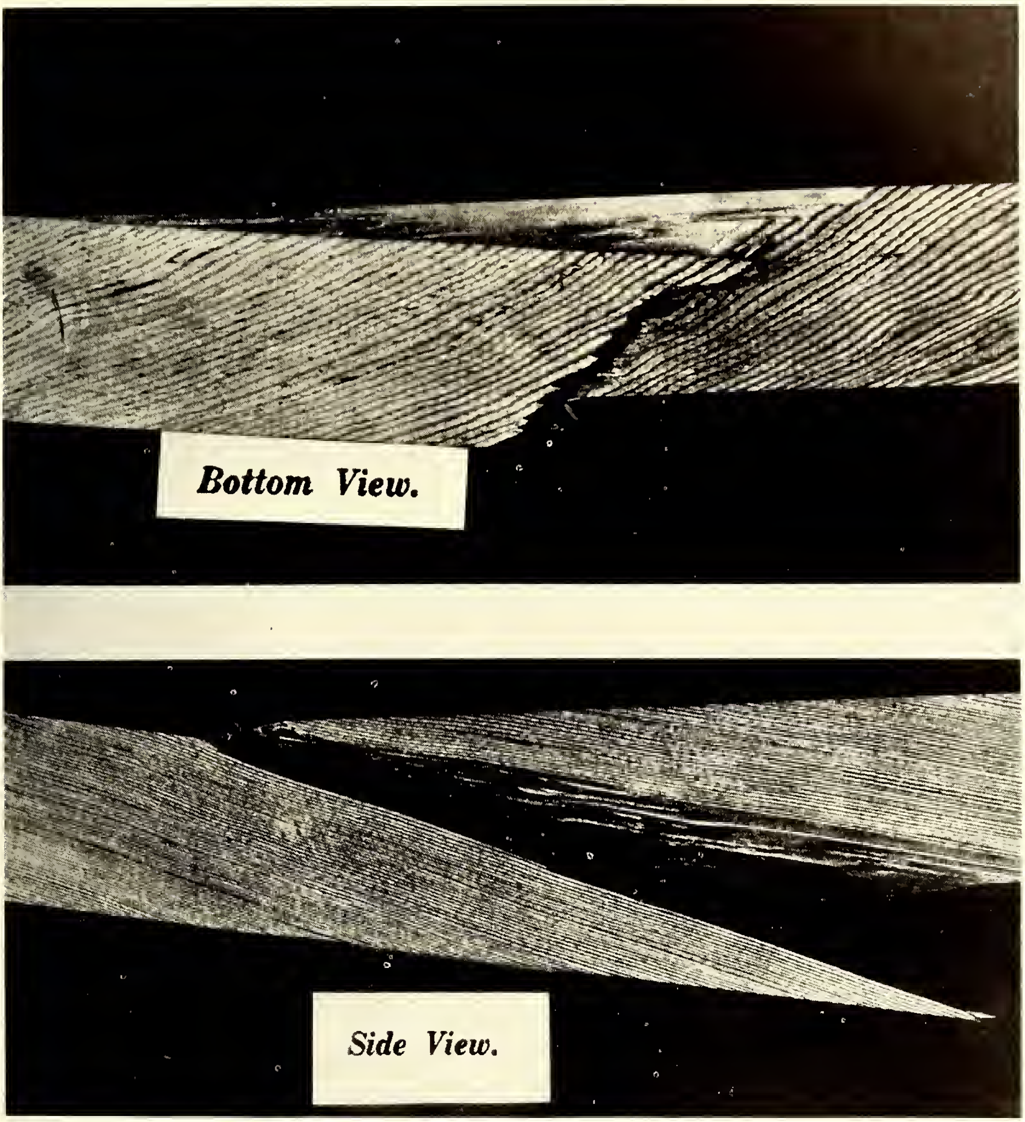

FIGURE 2–51.—Typical break in diagonal-grained specimen (Douglas-fir).

as at A, because the exact boundaries of the knot can be determined more accurately as a rule than the boundaries of the surrounding 45° wood and because admissible knot sizes are intended to apply only to the knot itself. Figure 2–50 also shows a cross section of a knot of equal size as seen on the edge grain; in this view the change in direction of the rings as they approach the knot is plainly seen.

2.302. Cross Grain. Cross grain in wood means that the fibers are not parallel with the major axis of the piece.

Cross grain is objectionable when excessive because it reduces strength, may cause warping in drying, and makes it difficult to surface wood smoothly when planing against the grain.

Cross grain may be either of two major types, namely, diagonal grain (fig. 2–51) or spiral grain (fig. 2–52), or a combination of the two.

2.3020. Diagonal Grain. Diagonal grain is deviation of the plane of the annual rings from parallelism with the longitudinal axis of a piece of wood. It is due to such natural causes as crook, bulges, butt swell, pitch and bark pockets, blister grain, some types of curly grain, healing over of knots and injuries, and to the common practice of sawing tapered logs parallel to the pith instead of to the bark.

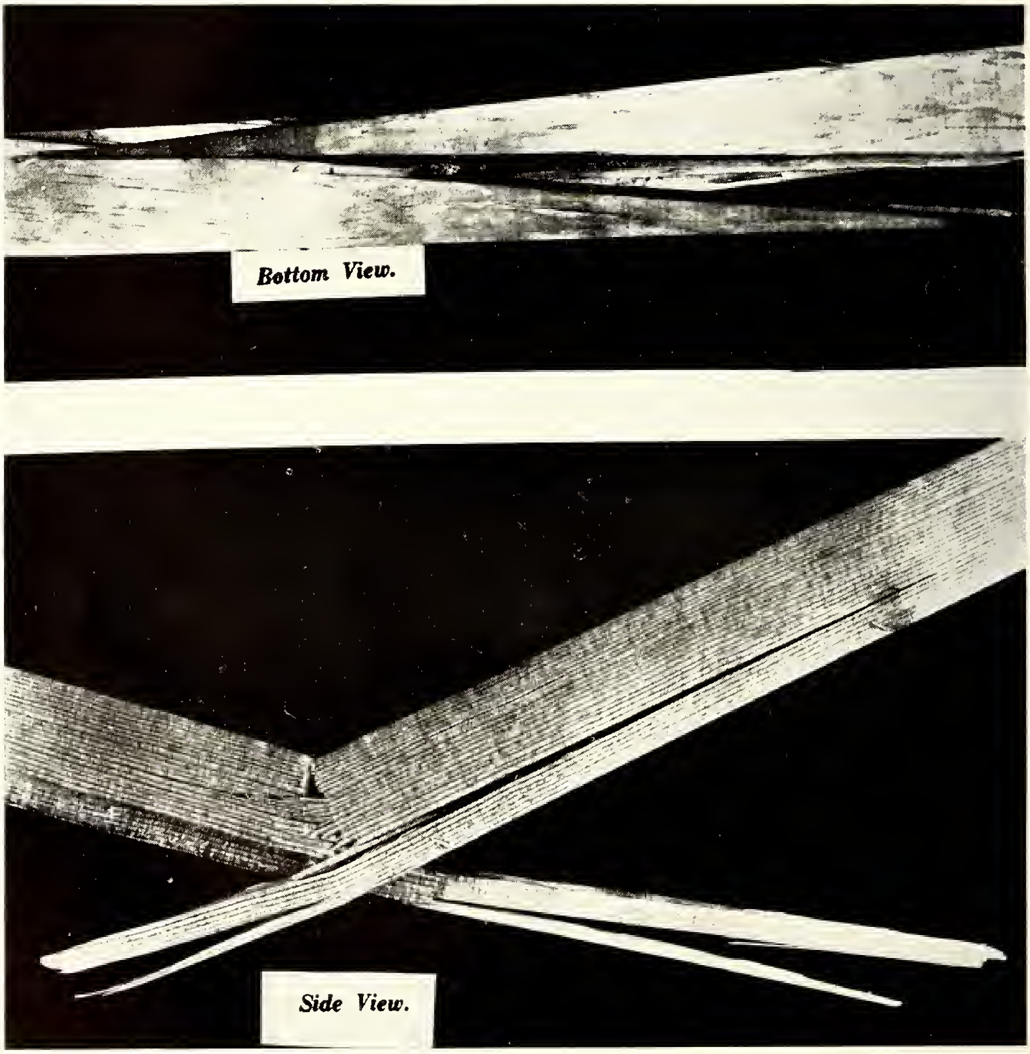

FIGURE 2–52.—Typical break in spiral-grained specimen (Sitka spruce).

Slope of grain is usually expressed as the number of units in which a deviation of one unit occurs. (The smaller the number of units in which unit deviation occurs, the steeper is the slope. Thus, 1 in 16 is a steeper slope than 1 in 18.)

For convenience, the slope of grain in the radial plane, no matter what its cause, is usually spoken of as diagonal grain. Since diagonal grain is usually more easily detected than spiral grain, examination should first be made for diagonal grain. If its slope is steeper than permissible, an examination for spiral grain need not be made.

2.3021. Spiral Grain. Due to an unknown cause, the fibers in some trees are not vertical but follow a spiral course similar to the stripes on a barber pole or a stick of candy. Spiral grain in peeled posts, poles, or tree trunks is evidenced by inclined rather than vertical season checks, as in the dead tree to the left in figure 2–53. The spiral is more often right-handed, as in a right-hand screw thread, in the tree. Ordinarily, the steepness of the spiral decreases from the bark toward the pith of the tree but this is not universally true. Also, the slope of the spiral sometimes fluctuates, especially near the butt of the tree, so that a block split radially will show a ruffled or fluted appearance as in figure 2–54.

Figure 2-53.—Straight grain and right-hand spiral indicated by direction of seasoning checks in dead tree trunks.

Truly straight-grained lumber cannot be produced from spiral-grained trees, but with wide flat-sawn boards or cants sawed some distance from the pith, the slope of the spiral can be reduced by proper attention in edging and ripping such pieces into smaller ones. On the other hand, false or artificial spiral grain is produced when straight-grained timber is not cut parallel to the fibers as seen on the tangenital surface. Superficially, it has the appearance of natural spiral grain and should be similarly regarded. It can sometimes be distinguished from natural spiral grain, however, by the fact that the slope does not change from one side to the other and, therefore, when the piece is split radially the split surface will be flat, whereas in naturally spiral-grained wood, the changing direction of the spiral may cause the split surface to be twisted.

When spiral grain is present, the principal evidence on a radial surface of a piece is the tendency for the surface to be chipped in planing and for a splinter raised by a knife point to run into the piece instead of tearing out to a uniform depth.

The principal indicators of the fiber direction on a truly tangential (plain-sawed or flat-grained) surface are checks, pores, resin ducts (fine, brownish lines in the pines, spruces, Douglas-fir, and tamarack), wood rays (most conspicuous in the oaks), the course taken by a scribe used as described later in this section, the direction in which a free flowing ink or dye spreads, the course taken by a narrow strip lifted by a knife point or turn out, and the surface splits formed when a sharp pointed tool, such as a chisel, is pushed into the piece and subjected to a prying action.

The scribe test consists in drawing a sharply pointed steel scribe in the direction in which the grain seems to run. Enough pressure must be applied so that the point will penetrate the wood slightly and freedom of lateral movement must be enough to allow the point to follow the grain. When properly used, the scribe test is one of the best methods for determining the direction in which the grain runs on a surface of a piece of wood if slight scratching of the surface is permissible. Figure 2–55 illustrates four scribes, *A*, *B*, *C*, and *D*, that have been found satisfactory. In *A* and *B* the point trails about 5 inches behind the vertical handle by means of which it is pulled, which gives it somewhat greater freedom of lateral movement than can be obtained with *C* and *D*. Scribe *A* has further advantages over *B* in that the handle is swiveled; the point, which is a phonograph needle, can easily be replaced; and the long tapered head on the set screw that holds the phonograph needle in place can be used to line up the direction in which the scribe is pulled with the path it has recently traversed. Scribes *B* and *C* are simpler to construct, since they are made of one piece of drill rod with one end tapered and hardened. *B* is more difficult to sharpen properly than *C*, since the point must be a perfect cone in order to function well. Scribe *D* consists of a phonograph needle held in a mechanical pencil. It has been found that the points follow the grain best if inclined 10° to 20° from the vertical toward the direction in which they are pulled.

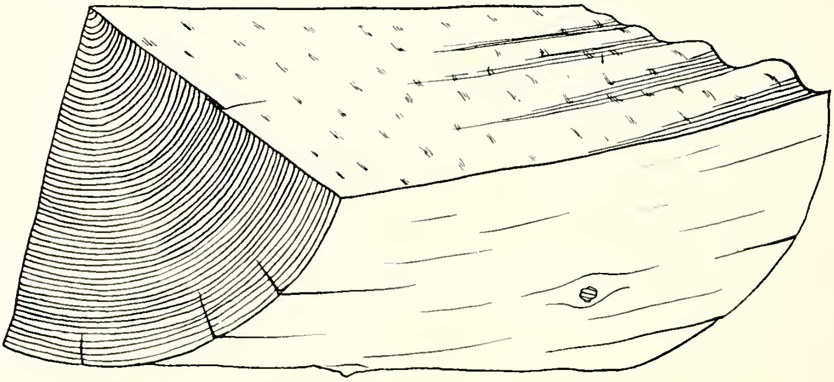

FIGURE 2–54.—Left-hand spiral grain of varying or fluctuating slope indicated by split radial surface.

In using the scribes it is advantageous to make one trial scratch, pulling the scribe in the direction in which the grain appears to run and then making a second scratch near to the first one by pulling the scribe in the direction parallel to the first one unless it obviously did not follow the grain. Bands of summerwood may deflect the scribe from following the true course of the fibers. In that case a number of short scratches should be made in the springwood only.

Figure 2–56 shows a number of scratches made with three different kinds of scribes. Their approximate parallelism for each scribe indicates a high degree of consistency and the way they follow the split, wavy edges of the birch veneer indicates accuracy in following the true direction of the grain.

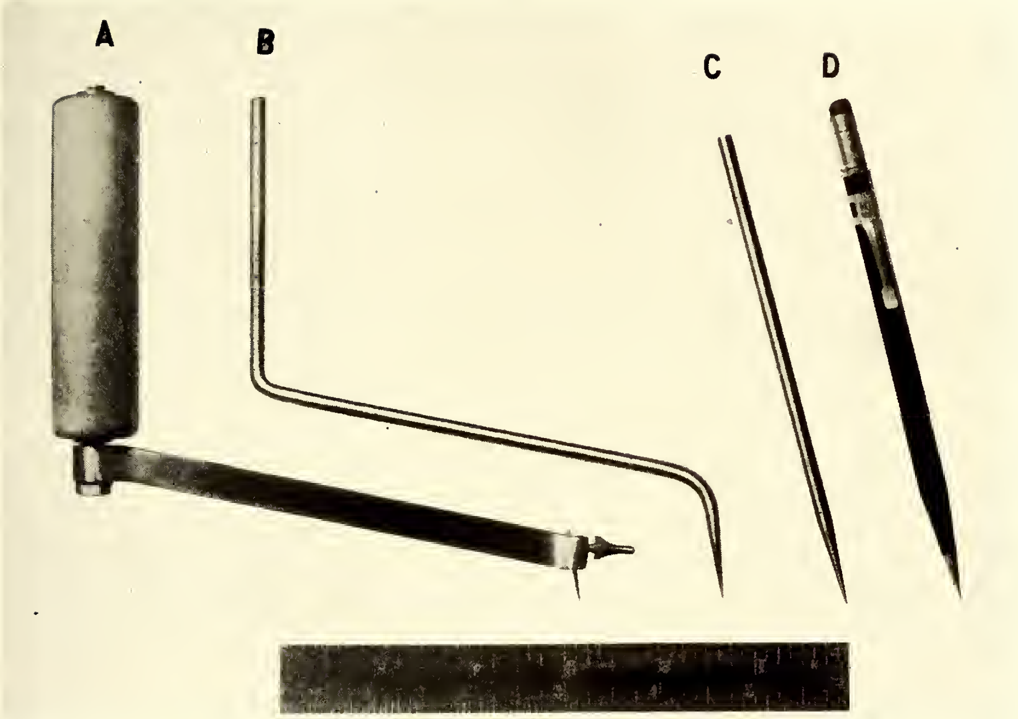

FIGURE 2-55.—Scribes for determining direction of the fibers on the surface of wood. *A*, Swivel-handled with phonograph-needle point; *B*, one-piece drill rod bent to shape and point slightly hardened; *C*, a straight piece of drill rod with point slightly hardened; *D*, mechanical pencil with phonograph-needle point.

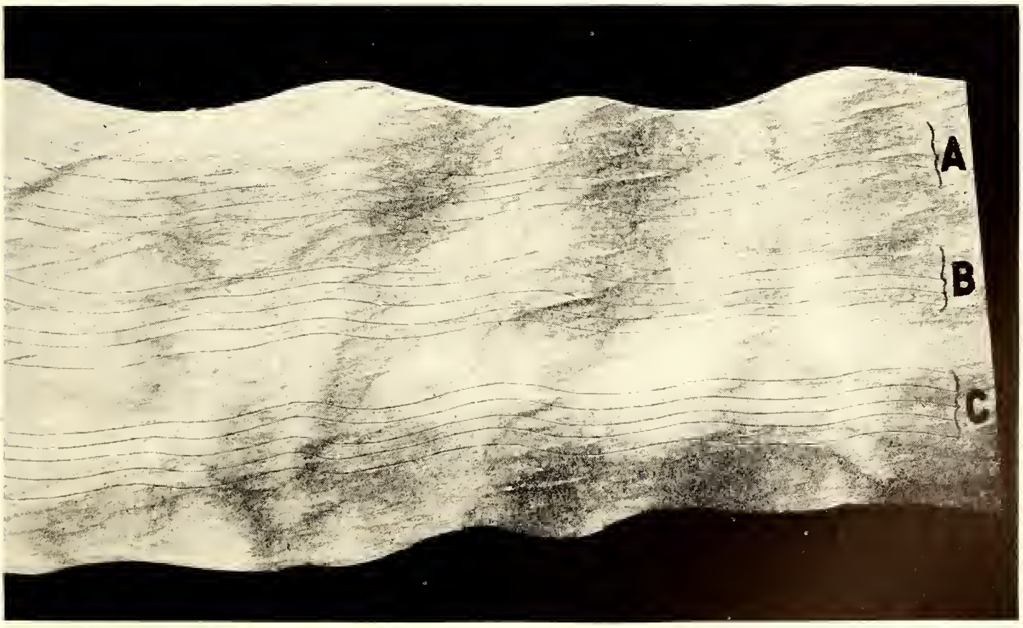

FIGURE 2-56.—Tangential surface of wood tested with scribes to determine direction of grain. Note parallelism of scribe marks in same areas.

It should be emphasized that the scratches made by the scribes follow the direction of the fibers on the surface and do not necessarily indicate the true slope of spiral grain, unless the surface is tangential or practically so.

2.3022. Combination of Diagonal and Spiral Grain. When a piece has diagonal and spiral grain in combination, the true slope of the fibers may be found by the use of table 2–11 or by computations after expressing the measured slopes to the same base. Thus, if the slope of spiral is 1 in 20 (equivalent to $1\frac{1}{2}$ in 30), and if that of the diagonal grain is 1 in 30, the combined slope, or the true slope of the fiber is $\sqrt{(1\frac{1}{2})^2+(1)^2}$ in $30=1.8$ in 30, which is the same as 1 in $\frac{30}{1.8}$ or 1 in $16\frac{2}{3}$. The computation of the above example also can be made by reducing the slopes to decimals (namely, 1 in $20=0.05$ and 1 in $30=0.033$) squaring these and taking the square root. Thus: $\sqrt{(.05)^2+(.033)^2}=\sqrt{.0025+.001089}=\sqrt{.003589}=0.06$, which corresponds to a slope of 1 in $16\frac{2}{3}$.

Table 2–11.—*Combined slope of spiral and diagonal grain*[1]

Slope of spiral or diagonal grain, whichever is flatter	Slope of spiral or diagonal grain, whichever is steeper																			
	1–10	1–11	1–12	1–13	1–14	1–15	1–16	1–17	1–18	1–19	1–20	1–21	1–22	1–23	1–24	1–25	1–26	1–27	1–28	1–29
1–10	7.1																			
1–11	7.4	7.8																		
1–12	7.7	8.1	8.5																	
1–13	7.9	8.4	8.8	9.2																
1–14	8.1	8.7	9.1	9.5	9.9															
1–15	8.3	8.9	9.4	9.8	10.2	10.6														
1–16	8.5	9.1	9.6	10.1	10.5	10.9	11.3													
1–17	8.6	9.2	9.8	10.3	10.8	11.2	11.7	12.0												
1–18	8.7	9.4	10.0	10.5	11.1	11.5	12.0	12.4	12.7											
1–19	8.8	9.5	10.1	10.7	11.3	11.8	12.2	12.7	13.1	13.4										
1–20	8.9	9.6	10.3	10.9	11.5	12.0	12.5	13.0	13.4	13.8	14.1									
1–21	9.0	9.7	10.4	11.1	11.6	12.2	12.7	13.2	13.7	14.1	14.5	14.9								
1–22	9.1	9.8	10.5	11.2	11.8	12.4	12.9	13.5	13.9	14.4	14.8	15.2	15.6							
1–23	9.2	9.9	10.6	11.3	12.0	12.6	13.1	13.7	14.2	14.6	15.1	15.5	15.9	16.3						
1–24	9.2	10.0	10.7	11.4	12.1	12.7	13.3	13.9	14.4	14.9	15.4	15.8	16.2	16.6	17.0					
1–25	9.3	10.1	10.8	11.5	12.2	12.9	13.5	14.1	14.6	15.1	15.6	16.1	16.5	16.9	17.3	17.7				
1–26	9.3	10.1	10.9	11.6	12.3	13.0	13.6	14.2	14.8	15.3	15.9	16.3	16.8	17.2	17.6	18.0	18.4			
1–27	9.4	10.2	11.0	11.7	12.4	13.1	13.8	14.4	15.0	15.5	16.1	16.6	17.1	17.5	17.9	18.3	18.7	19.1		
1–28	9.4	10.2	11.0	11.8	12.5	13.2	13.9	14.5	15.1	15.7	16.3	16.8	17.3	17.8	18.2	18.6	19.1	19.4	19.8	
1–29	9.5	10.3	11.1	11.9	12.6	13.3	14.0	14.7	15.3	15.9	16.5	17.0	17.5	18.0	18.5	18.9	19.4	19.8	20.1	20.5

[1] Based on formula: Combined slope of grain $=\sqrt{(\text{slope of spiral grain})^2+(\text{slope of diagonal grain})^2}$.

How to Determine Combined Slope of Spiral and Diagonal Grain

First, determine slopes of spiral and of diagonal grain separately. To determine the combined, or resultant, slope find the column headed by the steeper of the two slopes and in this column locate the figure in line with the flatter of the two slopes as given in the left-hand column. This figure represents the length in inches (or other units) in which the grain deviates 1 inch (or other unit) with respect to the central axis of the piece.

Examples: If the slope of spiral grain is 1 in 20 and the slope of diagonal grain is 1 in 25, the combined slope is 1 in 15.6, or if the slope of diagonal grain is 1 in 18 and the slope of spiral grain is 1 in 22, the combined slope is 1 in 13.9.

To get the true fiber direction, which is the slope of grain that determines the maximum effect on the strength properties, it is usually necessary to determine the slopes of spiral grain and of diagonal grain separately and to combine them by computation as just described.

2.3023. Detailed Methods for Determining Slope of Cross Grain. The following detailed methods for determining cross grain in boards whose original surfaces are truly tangential and radial and in those whose original surfaces are not truly tangential and radial, represent some of the less complex methods (fig. 2–57). A more complete discussion of methods for determining the direction of grain and measuring its slope is given in Forest Products Laboratory Mimeo. No. 1585.

A. Truly flat- (or quarter-) sawn board, no cross grain of any kind (fig. 2–57, *A*). *Description:* Annual rings on radial surface are parallel to edges of piece; fiber direction on tangential surface is parallel to edges.

B. Truly flat- (or quarter-) sawn board, spiral grain only (fig. 2–57, *B*). *Description:* Annual rings on radial surface are parallel to edges of piece; fiber direction on tangential surface is not parallel to edges of piece. *Method of measurement:* Draw line *ab* parallel to fiber direction indicators and measure *oa* and *ob*. Slope of spiral grain=*oa*/*ob*.

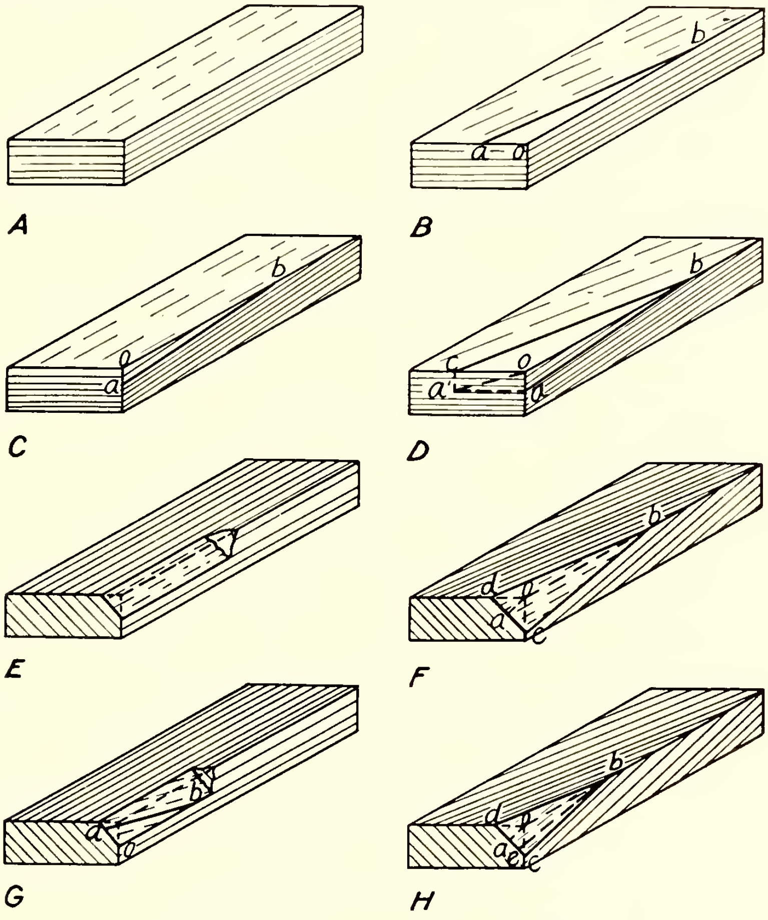

FIGURE 2–57.—Measurement of slope of grain.

C. Truly flat- (or quarter-) sawn board, diagonal grain only (fig. 2–57, *C*). *Description:* Annual rings on radial surface are not parallel to edges of piece; fiber direction on tangential surface is parallel to edge. *Method of Measurement:* Mark line *ab* parallel to annual rings and measure *oa* and *ob*. Slope of diagonal grain= *oa*/*ob*.

D. Truly flat- (or quarter-) sawn board, both spiral and diagonal grain (fig. 2–57, *D*). *Description:* Neither annual rings on radial surface nor fiber direction indicators on tangential surface are parallel to edges of piece. *Method of measurement:* Diagonal grain, locate line *ab* parallel to annual rings, slope of diagonal grain=oa/ob: spiral grain, locate line cb parallel to fiber direction indicators, slope of spiral grain=oc/ob; combined slope of grain, (1) locate lines aa' and ca' parallel to oc and oa, respectively, (2) combined slope of grain=oa'/ob: or calculate combined slope of grain from slope of spiral grain and slope of diagonal grain as explained in section 2.3022.

E. Board not truly flat- or quarter-sawn, no cross grain (fig. 2–57, *E*). *Description:* Annual rings are parallel to edges of piece; fiber direction indicators on tangential surface (exposed by splitting or shaving away some of the wood) parallel to edges of piece.

F. Board not truly flat- or quarter-sawn, diagonal grain only (fig. 2–57, *F*). *Description:* Annual rings not parallel to edges of piece; fiber direction on tangential surface (exposed as noted above) is parallel to edges of piece when viewed at right angles to exposed surface. *Method of measurement:* Diagonal grain, (1) select a point such as b which is either on the edge nearest the pith or farthest away from the pith; (2) trace the growth layer from b to c on the end; (3) thence from c across the end (which must be square with the long edges of the piece) to d; (4) then locate point a on line cd, where oa is the shortest distance from o to cd; (5) the slope of diagonal grain=oa/ob. Spiral grain, after having determined slope of diagonal grain, split or shave away wood to expose tangential surface and determine that fiber direction indicators are parallel to ob.

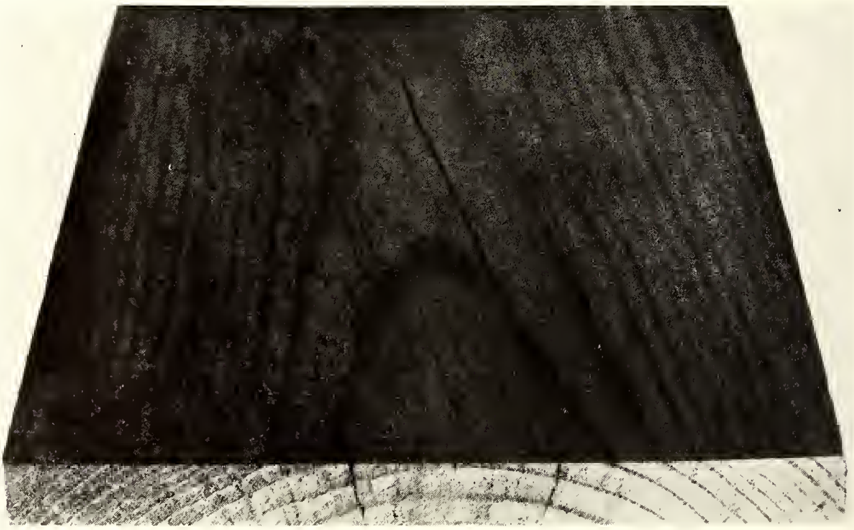

FIGURE 2-58.—Checks in a flat-grain board.

G. Board not truly flat- or quarter-sawn, spiral grain only (fig. 2–57, *G*). *Description:* Annual rings are parallel to edges of board; fiber direction on tangential surface (exposed as indicated above) not parallel to edges of piece. *Method of measurement:* Spiral grain, cut to expose tangential surface and locate line ab on tangential surface, parallel to fiber direction indicators, slope of spiral grain=oa/ob. If permissible, an alternate method is to split the wood radially and measure the slope of spiral grain directly.

H. Board not truly flat- or quarter-sawn, both diagonal and spiral grain (fig. 2–57, *H*). *Description:* Annual rings not parallel to edges of piece; fiber direction on tangential surface (as indicated above) not parallel to edges of piece when viewed at right angles to exposed surface. *Method of measurement:* Diagonal grain, as explained in (F) above; spiral grain, (1) after having located point a as described above, expose tangential surface as indicated above, (2) locate line *be* parallel to fiber direction indicators, (3) slope of spiral grain=*ae/ob;* combined slope of grain, (1) after having exposed tangential surface and located point *e* as explained above, lay a straightedge on the piece so that one edge lies along the line *ob*, (2) measure *ob*, (3) measure *oe*, (4) combined slope of grain=*oe/ob;* or determine combined slope of grain from slope of spiral grain and slope of diagonal grain as explained in section 2.3022. An alternate method is to split the wood radially and measure the slope of spiral grain directly.

2.303. Checks, Splits, and Shakes. A check is a longitudinal crack in wood, generally in the radial direction, or across the annual rings (fig. 2–58). Checks are usually due to uneven shrinkage in seasoning. Thick lumber checks more severely than thin lumber, and aircraft veneer is too thin to be subject to checking.

A split is a longitudinal crack in wood. It is caused by rough handling or other artificially induced stress. Typically it extends through the thickness of a piece from side to side regardless of whether the piece is edge-grained or flat-grained. When splits take a radial or tangential course they are not readily distinguishable from checks or shakes. Veneer, because of its greater fragility, splits much more readily than lumber.

Figure 2–59.—Shake in a flat-grain board.

A shake is a longitudinal crack in wood between two annual rings (fig. 2–59). Shakes, unlike checks and most splits, do not develop in seasoning or handling but originate in the green timber. They may, however, become accentuated in seasoning. Shakes would very seldom be encountered in either lumber or veneer approaching aircraft quality.

It is obvious that relatively large checks, splits, and shakes may seriously weaken wood members in resistance to longitudinal shear, and finished parts containing them should be rejected.

2.304. Pith Flecks. A pith fleck is a narrow streak resembling pith, usually brown in color and up to several inches in length, that results from the burrowing of larvae into the growing tissue of the tree. It is a defect of hardwoods rather than of softwoods and is probably most common in basswood, some species of birch, and maple, particularly soft maple. It varies considerably in different boards, from slight traces to a number of large streaks which might have an appreciable weakening effect,

FIGURE 2-60.—Pith flecks in basswood.

particularly in thin material such as veneer. Figure 2–60 shows pith flecks in basswood.

2.305. Compression Failures. Compression failures are deformations of the fibers due to excessive compression along the grain either in direct end compression or in bending. The deformations range from well-defined buckling of the fibers, visible to the unaided eye as wrinkles across the face of the piece (fig. 2–61), to slight crinkling of the fiber walls visible only with a high-power microscope.

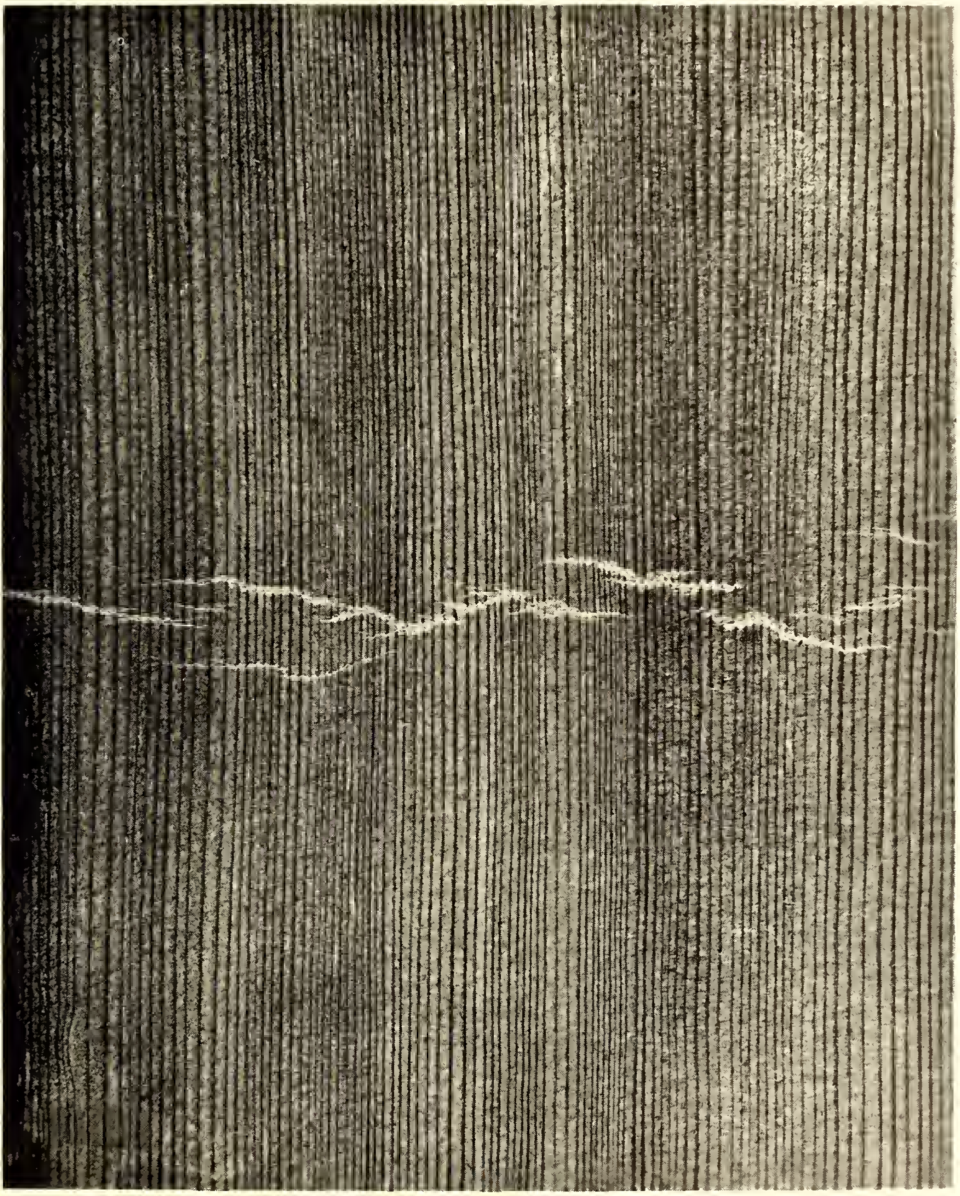

FIGURE 2–61.—Pronounced compression failure in Sitka spruce.

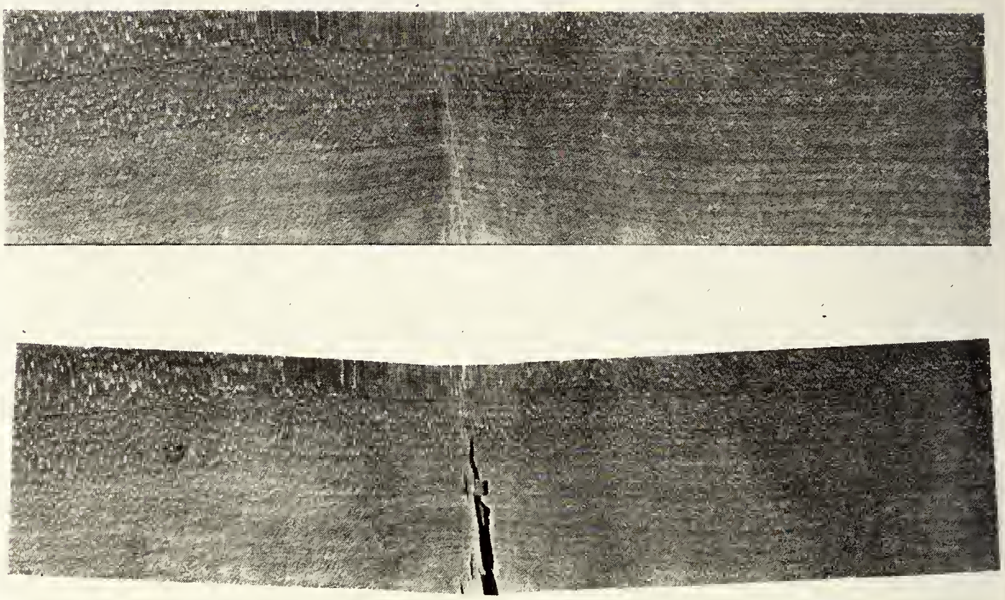

FIGURE 2-62.—Effect of compression failure in yellowpoplar beam. Top, piece containing compression failure as it appeared before application of load. Bottom, same piece after fracture. The compression failure on the tension side has caused an abrupt and complete fracture across the grain.

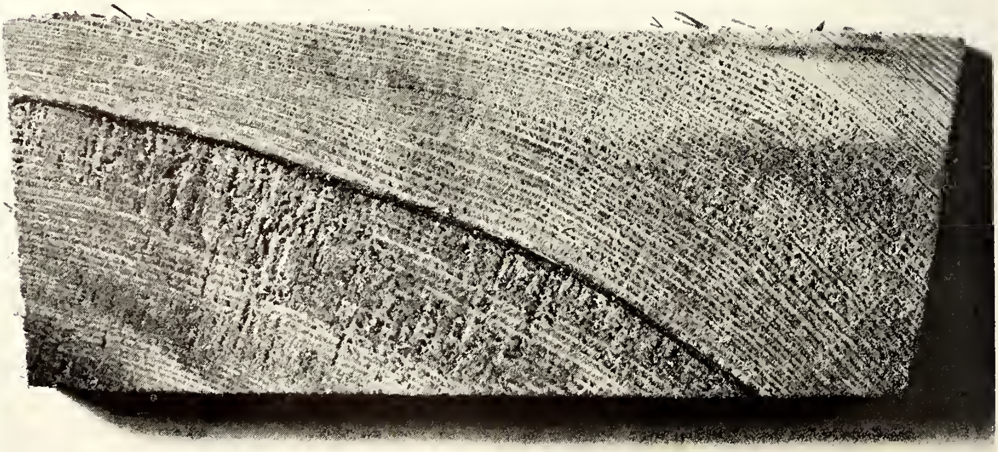

FIGURE 2-63.—Crosscut through Sitka spruce with numerous compression failures in the portion on the pith side of the black line, as indicated by the broken fibers in both summerwood and springwood.

They may develop when standing trees are bent severely by wind or snow, when timber is felled over irregularities of the ground, when logs and sawed stock are roughly handled, or from excessive stresses in service and, possibly, longitudinal stresses induced by the growth of the tree.

Compression failures, whether readily apparent to the eye or so fine as to be difficult to detect even with the aid of a microscope, seriously reduce the bending strength and shock-resisting capacity of wood. When present on the tension side of a bent member, they usually cause an abrupt and complete fracture across the grain under relatively low stresses (fig. 2–62). All material containing compression failures, therefore, is unsuitable for aircraft parts in which strength is of importance.

Compression failures can best be seen in wood so placed that light strikes along the fibers at an angle of about 20° with the surface. A source of concentrated light, such as a spotlight, is best. The piece should be viewed at angles of between 45° and 90° to the grain from the side on which the light is located. Other angles of light and vision should also be tried. When viewed in this manner, a failure appears as an irregular line extending across the grain, as shown in figure 2–61.

The presence of numerous minute compression failures may often be detected by the appearance of the crosscut surface, as in figure 2–63. On the pith side of the black pencil line in the figure, groups of springwood and summerwood fibers are shown broken off at minute compression failures close to the saw cut, rather than being cut off cleanly by the saw. This end breakage of fiber due to compression failures has a characteristic appearance regardless of whether the crosscut was made with a coarse or a fine saw. The fibers are broken off in more or less discontinuous, radial streaks, as shown in figures 2–63 and 2–64. On the bark side of the black line, where there are no compression failures, the normal appearance of a saw cut may be seen. Although the springwood is broken out in places, the summerwood is cut off throughout by the saw. Absence of end breakage of fiber is not proof, however, of the absence of compression failures, since the saw cut may not have come close enough to failures present within the piece.

The use of transmitted light is an aid in detecting compression failures in veneer. The sheet is held up to a bright light so that the side observed is in shadow. A compression failure will then appear as a dark, irregular line across the grain. Figure 2–65 shows a compression failure in yellowpoplar veneer as it appears using transmitted light. This method is usually more effective in light-colored woods, such as Sitka spruce, than in dark-colored woods, such as mahogany.

A good hand lens with a magnifying power of about 10 diameters is of assistance when the failures are not pronounced. In the laboratory, magnification up to 60 diameters by means of a low-power microscope is helpful.

When a toughness machine such as is described in Forest Products Laboratory Mimeograph No. 1308 is used as a part of the regular acceptance test, lumber containing even minute compression failures can in practically all cases be detected by the low toughness values obtained.

2.306. Compression Wood. Compression wood is an abnormal type of wood formed on the lower side of leaning softwood trees only—not in hardwood trees. Because of inferior strength properties, excessive longitudinal shrinkage, and relatively high specific gravity for a species, compression wood is unsuitable for aircraft construction except in limited amounts.

Compression wood usually has relatively wide annual rings and unusually wide summerwood which, however, does not appear so dense and hornlike as normal summerwood. This results in a lack of contrast with springwood which gives a lifeless appearance to compression wood, particularly when dry, as shown in figure 2–66. On surfaces of lumber and veneer, compression wood usually has a yellowish or slightly brownish color when dry and a reddish color when wet. Streaks of compression wood on edge-grain surfaces frequently are interspersed with streaks of normal wood, which usually has narrower annual rings, as is shown in figure 2-67. Occasionally it is present entirely across the width of pieces of edge-grain lumber.

Compression wood gradates from a pronounced to a border-line form which approximates normal wood in appearance, particularly that which has wide summerwood.

Well-developed compression wood usually can be detected in ordinary visual inspection by its relatively wide annual rings and wide summerwood. Moderately developed and border-line forms, as well as pronounced compression wood, can be detected by the opacity of their summerwood in contrast to the translucence of normal summerwood when thin sections are held against a bright light (fig. 2-68, *C*). A box, containing a 100-watt bulb and having a variable opening over which the thin section can be laid, when used in a darkened room or in a well-shaded position, is best for the purpose (fig. 2-69). The opacity of the summerwood of compression wood is due to the microscopically discontinuous structure of its fiber walls, which dissipate light, in contrast to the continuous dense fiber walls of normal wood.

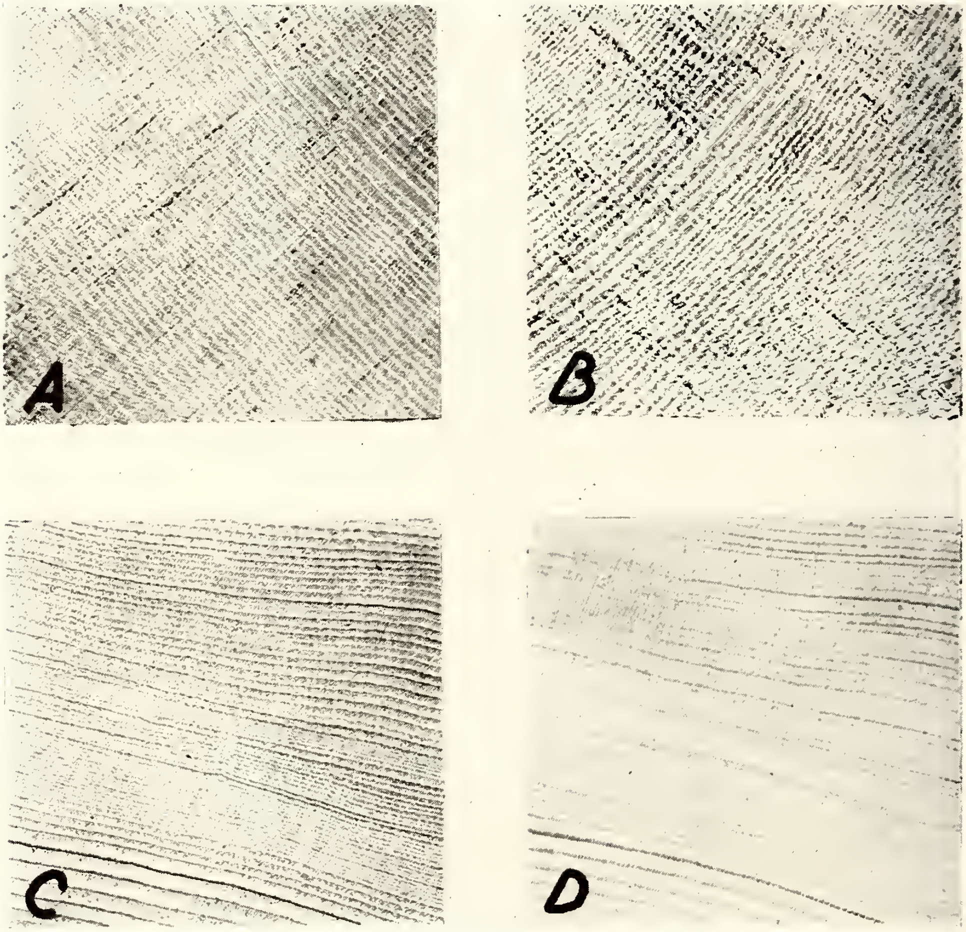

FIGURE 2-64.—Crosscuts through Sitka spruce. *A* and *C* cut with hollow ground cut-off saw; *B* and *D* cut with novelty cut-off saw. Discontinuous, radial streaks of fibers, broken of in sawing indicate the presence of compression failures in *A*. and *B* *C* and *D*, made with the same saws as *A* and *B*, respectively, show no evidences of compression failure.

For examining lumber for compression wood by transmitted light, cross sections approximately five thirty-seconds inch thick, cut with a smoothly cutting saw, have been found satisfactory for most species. In quarter-sliced veneer it also can be detected by this method in thicknesses up to one-eighth inch, at least. Even in glued panels, compression wood can be detected in the face plies by the opacity of its summerwood, provided the ply containing compression wood is on the side toward the observer, dark-colored heartwood of such species as yellowpoplar and sweetgum is not included in the panel, and the total thickness does not exceed about one-eighth inch. Figures 2–70 and 2–71 show compression wood (*left*) and normal wood (*right*) in veneer and plywood, respectively, as seen in ordinary visual inspection (*above*) and as seen against a bright light (*below*). In the latter, the summerwood of compression wood is shown as opaque, that of normal wood as translucent.

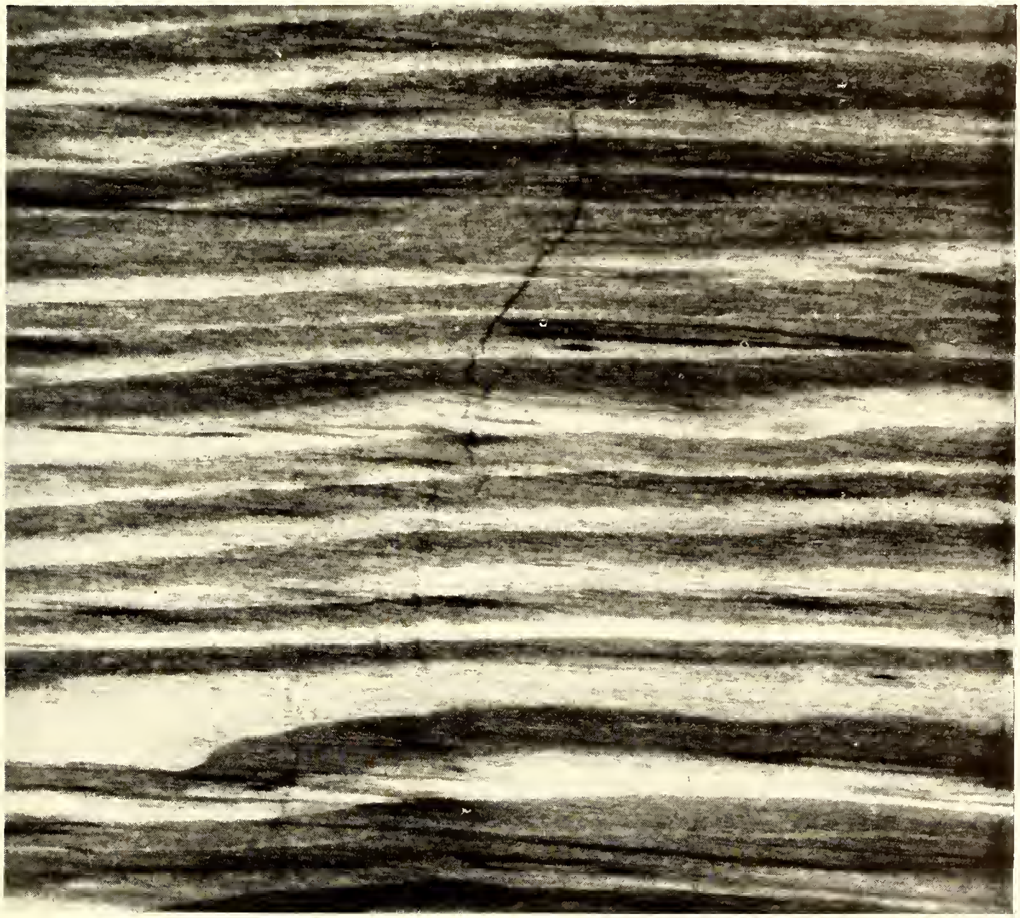

FIGURE 2–65.—Compression failure in rotary-cut yellowpoplar veneer by transmitted light.

Strength properties of compression wood, particularly stiffness and shock resistance, are lower than those of normal wood of the same species when dry. Other

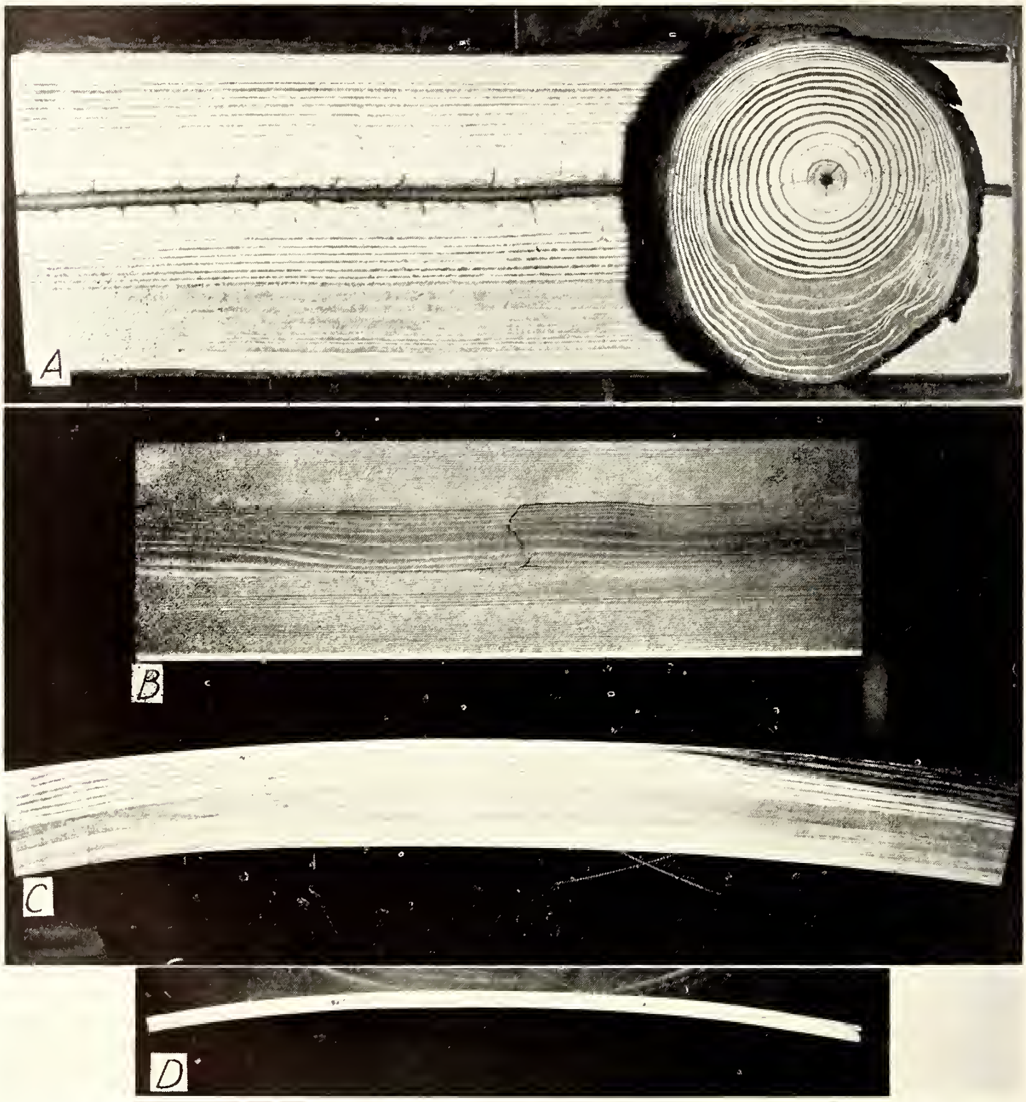

FIGURE 2–66.—*A*, longitudinal and cross sections through part of a tree trunk with compression wood on lower side; *B*, cross break in compression wood and splits between compression wood and normal wood due to greater longitudinal shrinkage of compression wood; *C*, crook caused by longitudinal shrinkage of the compression wood on the lower side; *D*, cupping in three-ply plywood due to higher longitudinal shrinkage of compression wood in the bottom ply than of the normal wood in the top ply.

bending-strength properties are erratic, since the tensile strength of compression wood frequently is much lower than that of normal wood. In bending, compression wood breaks with a brittle fracture, while normal wood splinters, as is shown in figure 2–68, *A*, *B*. Compression wood has relatively higher density than normal wood, so that the ratio of weight to strength also makes it unsuitable for aircraft structure. Excessive and irregular shrinkage along the grain of compression wood occasionally causes cross breaks and, frequently, crook and bow in lumber. Figure 2–66, *B*, shows a cross break in compression wood bounded on both sides by normal

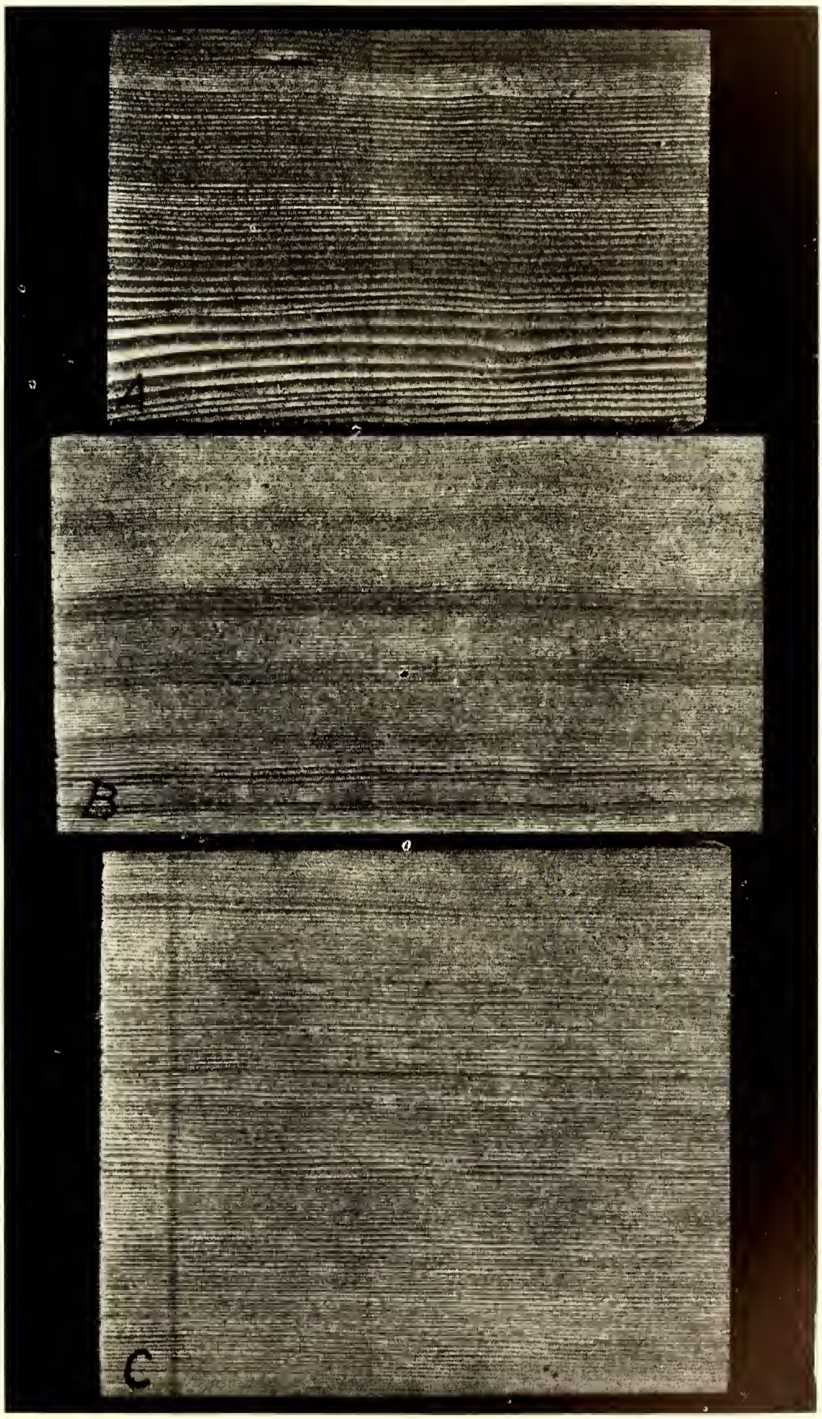

FIGURE 2–67.—Samples of western hemlock boards with compression wood in varying amounts: *A*, practically the entire surface; *B*, streaks interspersed with normal wood; and *C*, occasional annual rings. *A* and *B* have excessive amounts of compression wood, while that of *C* may be permitted.

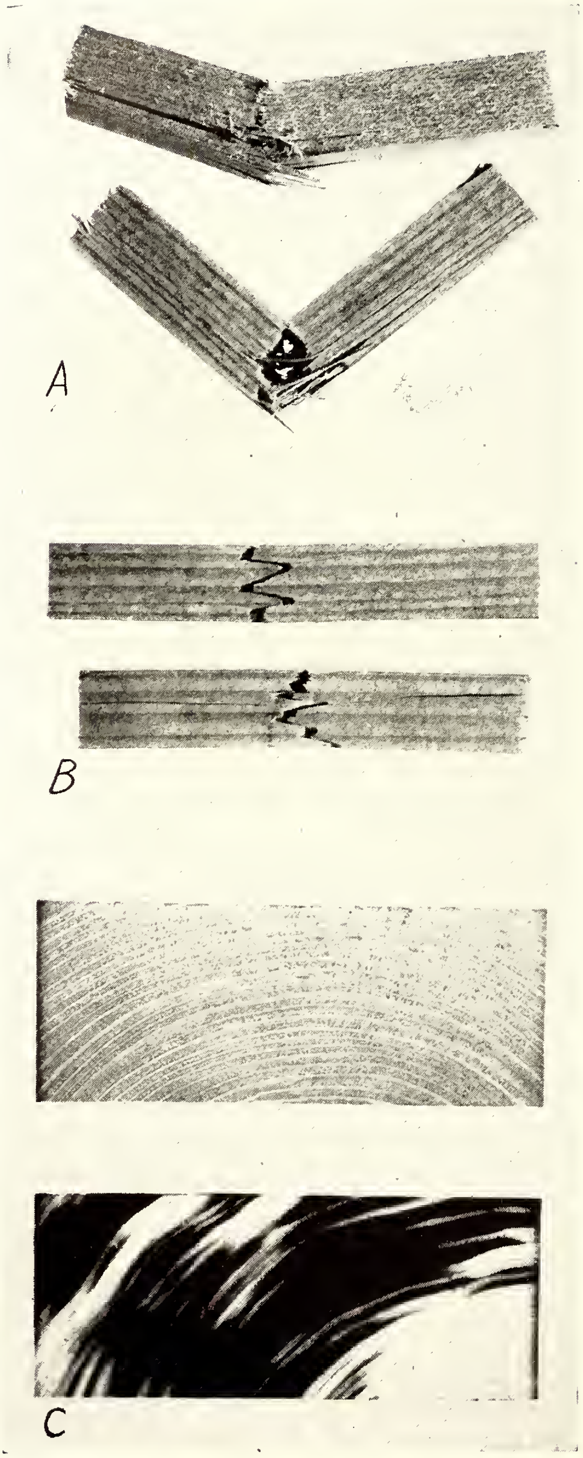

FIGURE 2-68.—Typical bending failures in Sitka spruce represented by: *A*, splintering normal wood, and *B*, brittle compression wood. In *C*, upper example shows cross sections of normal translucent wood five thirty-seconds inch thick photographed by transmitted light, summerwood more translucent than springwood; lower example shows compression wood interspersed with normal wood, compression wood indicated by its opaque summerwood.

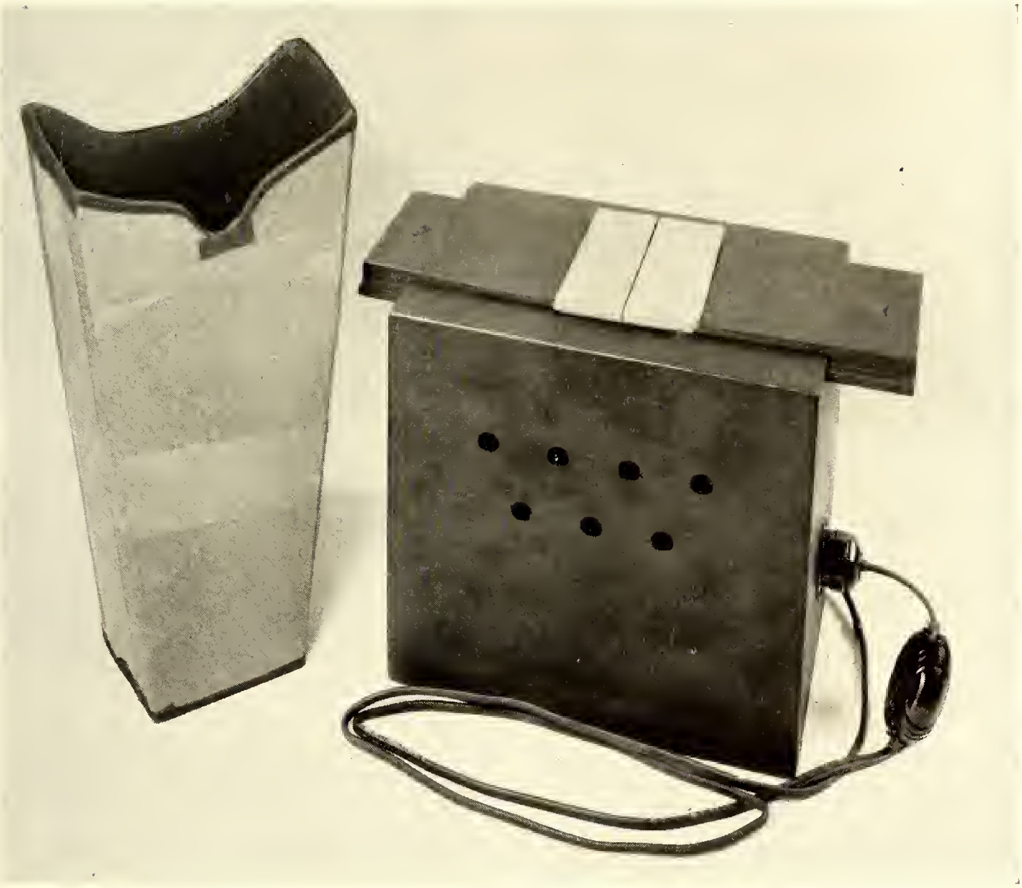

FIGURE 2-69.—Forest Products Laboratory apparatus for detecting compression wood by transmitted light.

wood, and figure 2-66, *C*, shows crook of a piece in which the compression wood is along one edge. These defects resulted from much greater longitudinal shrinkage in the compression wood than in adjacent normal wood. Figure 2-66, *D*, is an edge view of cupping in three-ply plywood that resulted from greater longitudinal shrinkage in compression wood in the ply on the lower face than in normal wood in the upper face ply.

The inferior strength properties, excessive longitudinal shrinkage, and greater density of compression wood generally are detrimental to aircraft structures. Compression wood may be permitted in aircraft structures only to the extent described in section 2.4.

2.307. Pitch Pockets. Pitch pockets are approximately plano-convex, lens-shaped openings within annual rings, usually longer than they are wide. As a rule, they contain more or less resin and, occasionally, bark. They may be from less than an inch to several inches in length. They normally occur only in certain conifers, namely, pine, Douglas-fir, spruce, tamarack, and larch. They are most common in southern pines and Douglas-fir and least common in redwood. They probably are the result of small injuries received at some time during its growth by the cambium, which is the growing layer between bark and wood. They are objectionable because they may weaken small members and resin may exude from them, especially when

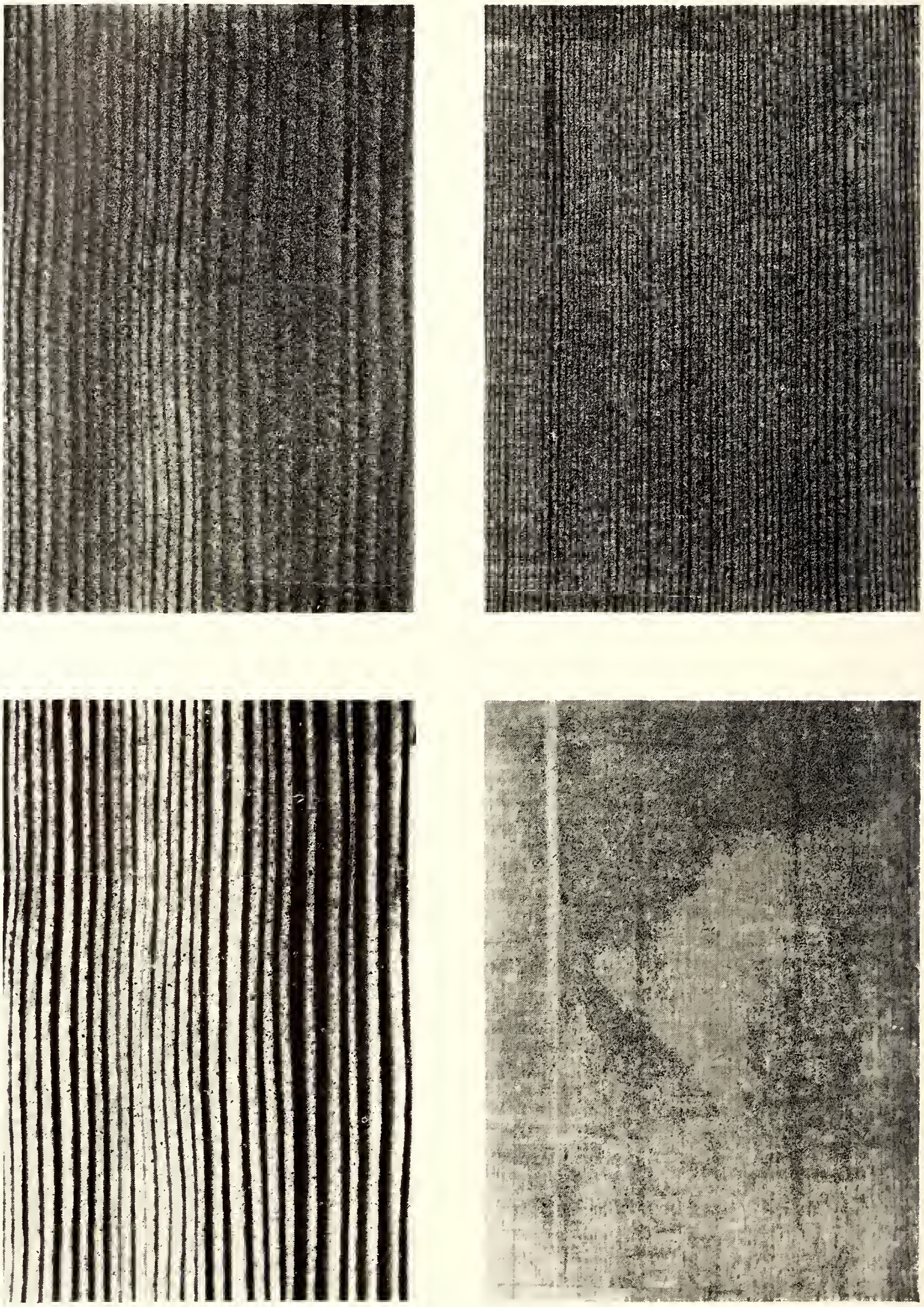

FIGURE 2-70.—Two pieces of Douglas-fir veneer photographed (*above*) by reflected light as seen in ordinary visual inspection and (*below*) by transmitted light. Note in the lower photographs (*left*) opacity of the summerwood of compression wood and (*right*) its translucence in normal wood, in which the summerwood is brighter than the springwood.

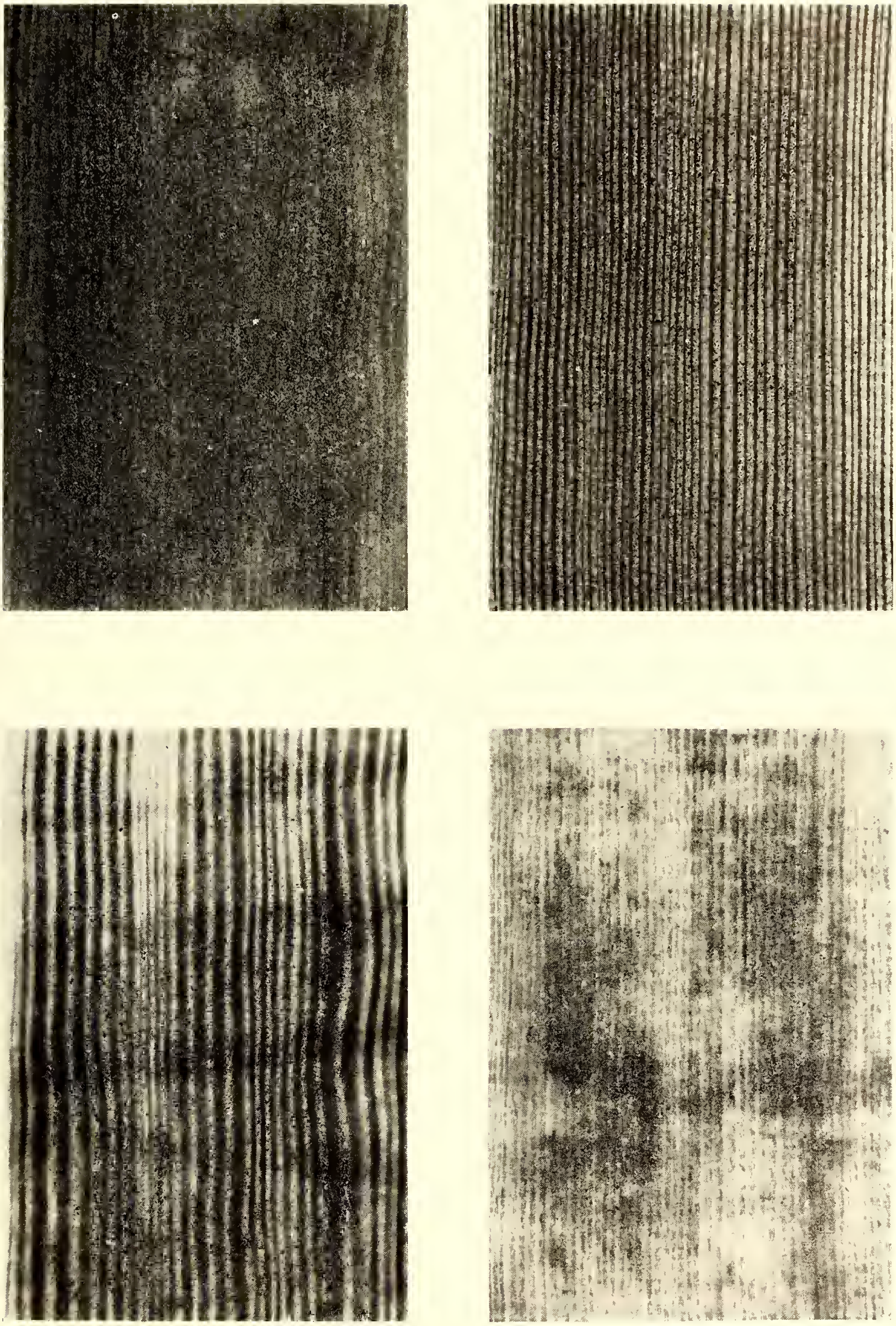

FIGURE 2-71.—Two pieces of Douglas-fir plywood photographed (*above*) by reflected light as seen in ordinary visual inspection and (*below*) by transmitted light. Note in the lower photographs (*left*) opacity of the summerwood of compression wood and (*right*) its translucence in normal wood, in which the summerwood is brighter than the springwood.

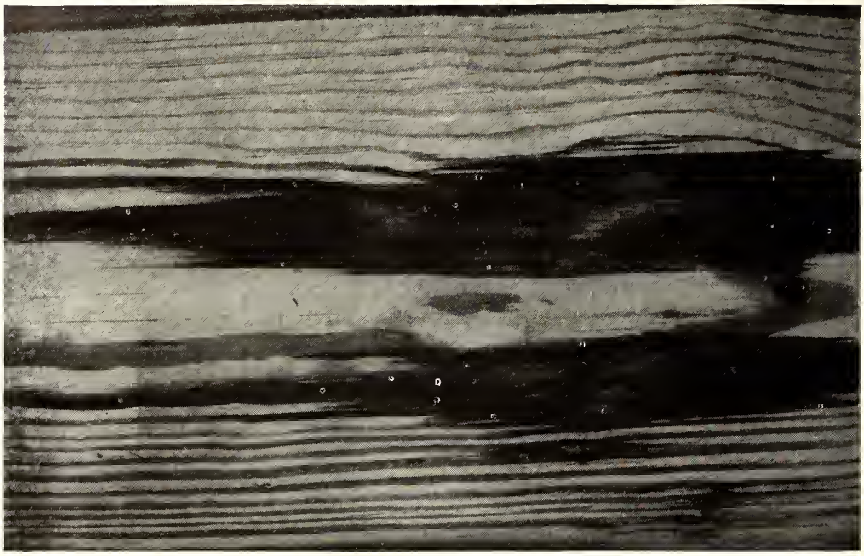

Figure 2-72.—Pitch streak.

Figure 2-73.—Mineral streak.

the wood becomes warm. In quarter-sliced veneer pitch pockets appear as narrow slits.

2.308. Bark Pockets. A bark pocket is a patch of bark partially or wholly enclosed in the wood. There is usually some slight separation, or at least a lack of cohesion, involved that has a definite weakening effect. They are occasionally found in most aircraft woods, particularly in spruce, and are considered equal in damaging effect to pitch pockets of equal size. In appearance they resemble pitch pockets more closely than any other defect; but they are usually smaller and, of course, lack pitch.

2.309. Pitch Streaks. Pitch streaks are well-defined infiltrations of resin in the fibers in the form of streaks, usually extending a greater distance along than across the grain (fig. 2–72). They normally occur only in pine, Douglas-fir, spruce, tamarack, and larch. As found in the better grades of lumber, practically all are small.

Pitch streaks are objectionable in airplane constructions in that the pitch may add materially to the weight of the wood; it may exude, especially in warm weather, and affect those finishes which do not hold well on pitchy areas.

2.310. Mineral Streaks. Mineral streaks are dark brown or black streaks, frequently with a green tinge, and often contain mineral matter in sufficient quantities to dull sharp-edged tools. They vary in length from less than an inch to a foot or more along the grain and have a transverse dimension at the widest portion of one-eighth inch to 1 inch or more (fig. 2–73). Their limits may be sharply defined, or they may fade out gradually into the surrounding wood. Mineral streaks are frequently infected by fungus, and they check more easily in seasoning than does normal wood.

Mineral streaks are common in maple, hickory, basswood, yellowpoplar, and yellow birch and are occasionally found in other hardwoods. Evidently they are often, if not always, due to some injury that the living tree received in the form of bird pecks, mechanical abrasion, tappings for maple sugar, or the like.

2.311. Indented Rings. In certain species of conifers, particularly Sitka spruce, annual rings as seen on the cross section sometimes are indented along a radial line for many successive years (fig. 2–74). Each indentation usually extends up and down the tree trunk for several inches, producing noticeable blemishes on longitudinal, especially tangential, surfaces (fig. 2–75). If the indentations ran exactly parallel to the grain, they would produce no distortion of the individual fibers except at the top and bottom ends of the indentation; but, since they usually make a slight angle with the grain, the fibers dip from their straight longitudinal course at the indentation, like a slack rope on the ground in following the contour of a ditch which it crosses at a very acute angle.

This dip is in a radial direction and causes a slight curvature of the annual rings and deflection of the fibers in a radial plane, as shown in figure 2–76. In a tangential plane, on the other hand, the indented rings cause no distortion of grain, as is evidenced by figure 2–75, in which the checks are not deflected as they pass through the indented portion.

2.312. Burls. A burl, as defined with respect to aircraft veneer specifications, is a local distortion of the grain due to one or several contiguous conical protuberances of wood on the tree trunk which are formed under dormant buds that usually do not develop but persist for many years, each having a core, or pith, or to overgrowths of such buds that died and no longer contain a pith (fig. 2–77). Sometimes a large number of such buds are produced in close proximity to each other, forming a large, wartlike excrescence on the tree trunk, which is the popular conception of a burl. Burls may occur singly or in groups with areas of straight-grained wood between them. Because burls originate from conical projections, they usually show a fairly definite boundary in lumber and veneer.

FIGURE 2-74.—Indented rings as seen on a cross section of Sitka spruce. Natural size.

FIGURE 2-75.—Indented rings as seen on a tangential surface of Sitka spruce. Natural size.

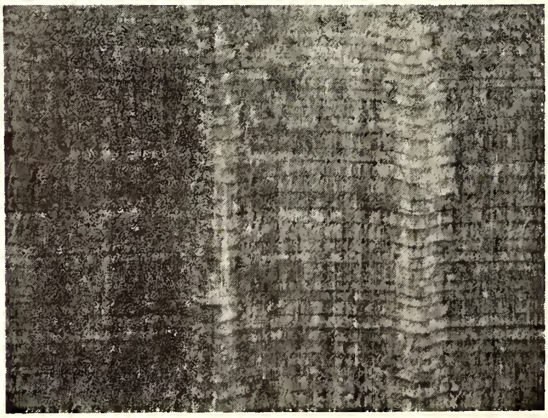

FIGURE 2-76.—Indented rings as seen on a radial surface of Sitka spruce.

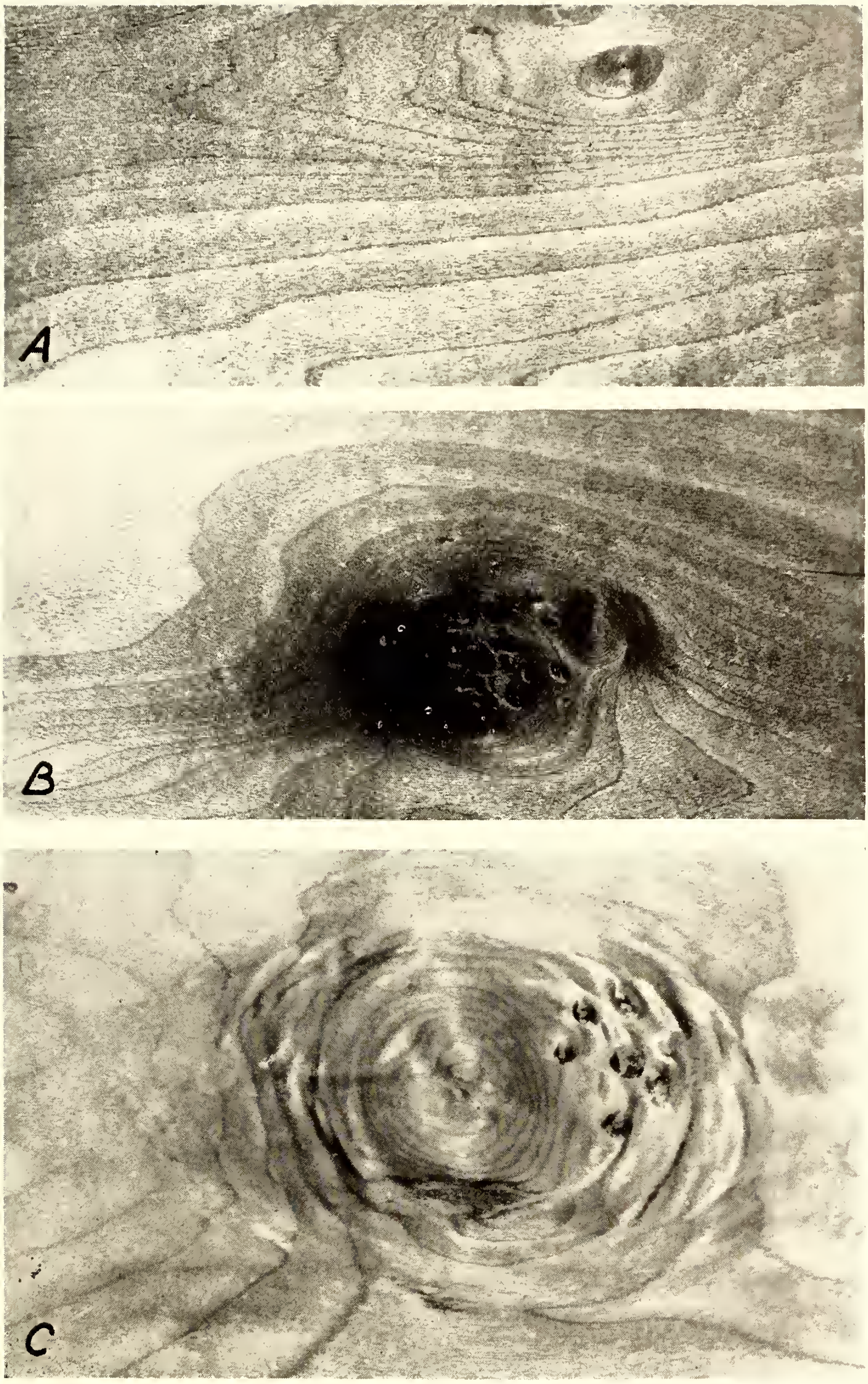

FIGURE 2-77.—Burls in yellowpoplar rotary-cut veneer. *A*, A burl formed by one conical elevation below a dormant bud. Note dark core, or pith, and flat grain on both sides, as indicated by reflection of light and pore length. *B*, A burl formed by a cluster of dormant buds. *C*, Six small burls associated with cross grain due to overgrowth of knot.

A tangential cut through the conical protuberance of a burl frequently resembles a small knot in having a central pith but differs from it in that there is no appreciable amount of strictly end grain around the pith. There may be steep cross grain on the upper and lower sides of such a conical elevation, but on the two lateral sides the grain is practically flat (fig. 2–77, *A*).

A burl differs from cross grain formed by rounded protuberances due to overgrowth of a knot or injury or crook in the tree trunk, in that in such cross-grained areas there is no central pith and the grain at the center of such a protuberance is flat in tangential view, although it may be curly, and more or less steep slope of grain occurs some distance above and below the center (figs. 2–77, *C*, and 2–78). In such rounded protuberances the cross grain usually is less steep than in burls.

Burls differ from bird's-eyes in that the latter are due to individually scattered conical depressions and never have a pith center.

On account of the differences in the steepness and distribution of cross grain in them, it is necessary to distinguish between knots, burls, and rounded protuberances, the burls usually being intermediate in weakening effect between the other two.

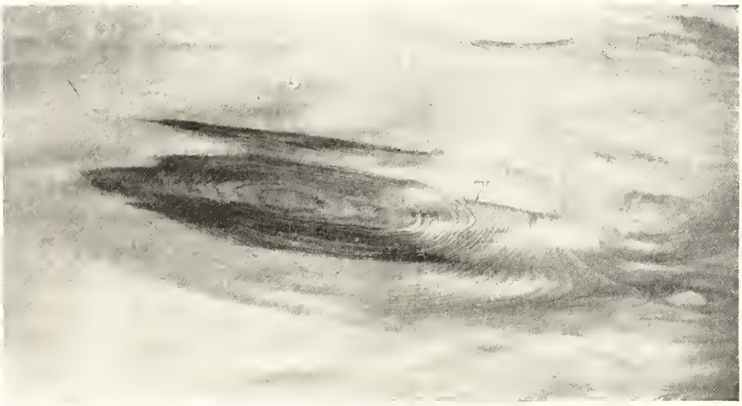

Figure 2–78.—Type of figure produced in cutting rotary veneer from a block with some crook; not to be confused with large burl.

2.313. Bird's-eye. Bird's-eye is defined as a small, central spot around which the wood fibers are arranged in the form of an ellipse to give the appearance of an eye. Bird's-eye is fairly common in maple. Some samples show a sparsely scattered bird's-eye, as in figure 2–79, while others show bird's-eyes crowded in at the rate of 10 or more per square inch. Since each bird's eye is accompanied by a small area of steep cross grain, the effect on strength may be considerable in pieces of the latter type. Yellow birch occasionally exhibits a dimple-like effect that is sometimes called bird's-eye, although it has a less pronounced figure than bird's-eye in maple. Among softwoods, redwood has a so-called bird's-eye that is found in many pieces in the clear grades. This bird's-eye usually occurs in small, rather widely scattered chains, hence it is not discriminated against unless hollow or unsound.

2.314. Radial Red Streak in Spruce. Radial red streaks in spurce are noticeably darker than the surrounding wood, especially as seen on the edge-grain face, and may extend across a number of annual rings. Their vertical height is usually less than their radial extent (fig. 2–80). The color is caused by the presence of dark gummy material in the wood ray cells. The gum-containing rays may be considerably higher vertically than normal rays (that is, made up of more cells one above another). No indication has been found that the red streaks are, in themselves, a source of weakness in the wood containing them. Sometimes they are associated with distorted grain, the effect of which should be determined independently.

2.315. Giant Resin Canals in Spruce. Radial resin canals with diameters up to one-eighth inch or more, so large that they are easily seen by the naked eye and consequently are sometimes mistaken for worm holes, may occur in spruce wood. Large vertical resin canals may also occur but are much less frequent than radial canals. In figure 2–81 the relative size of the normal and of giant resin canals is shown.

In determining when wood with giant resin canals should be rejected, the strength requirements of the part and the number of canals present per unit area should be considered. Since the resin canals do not produce serious distortion of the grain, their presence in low-stressed parts is, unless in obviously large numbers, not objectionable. Even in highly-stressed parts, the presence of occasional large canals should not be cause for rejection.

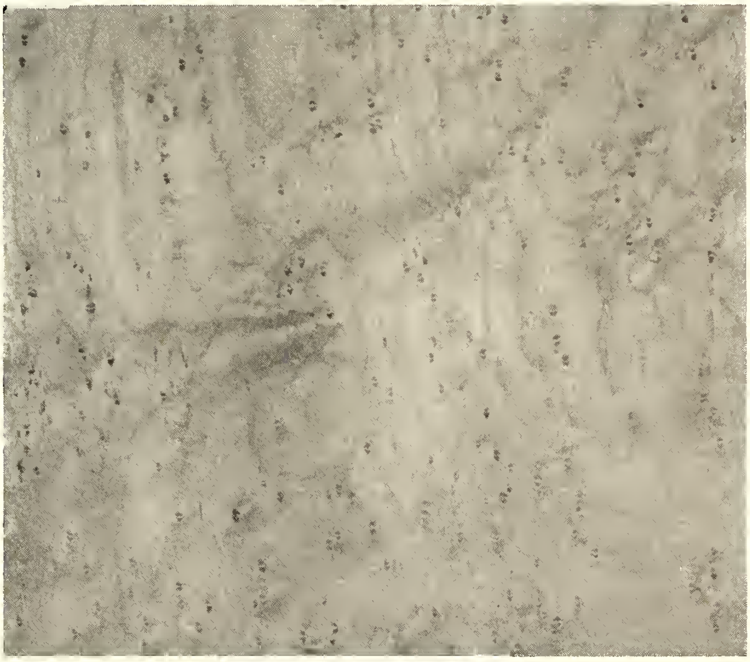

FIGURE 2–79.—Bird's-eye in maple.

2.316. Black Streaks in Western Hemlock and Other Coniferous Species. The activities of a species of fly (*Chilosia alaskensis* Hunter), living under the bark of certain coniferous species as a larva or maggot, result in the formation of a chamber or cavity in the wood which often resembles a pitch pocket in shape but is filled or lined with cellular tissue having dark-colored contents. Continuing vertically in both directions, from the maggot chamber for distances varying from a few inches to a few feet, is a thin layer of dark tissue which usually occupies only part of the thickness of an annual growth layer and is limited in circumferential extent to an inch or so. As seen on an edge-grained surface, the appearance is a thin black line which is wider where a maggot chamber is cut through. This gives rise to the use of the term "black streak" to designate the layer of dark tissue and the included maggot chamber.

Tests of the effect of black streaks indicate that except for the maggot chambers they need not be limited and that the chambers may be admitted in airplane parts to the same extent as pitch pockets. The length of a maggot chamber should

FIGURE 2-80.—Radial red streak in spruce as it appears on an edge-grain face.

be considered only as that of the definitely wider or thicker portion of the black streak (fig. 2–82).

Irregular grain or deviations of grain associated with maggot chambers should, of course, be limited in the same manner as other deviations of grain.

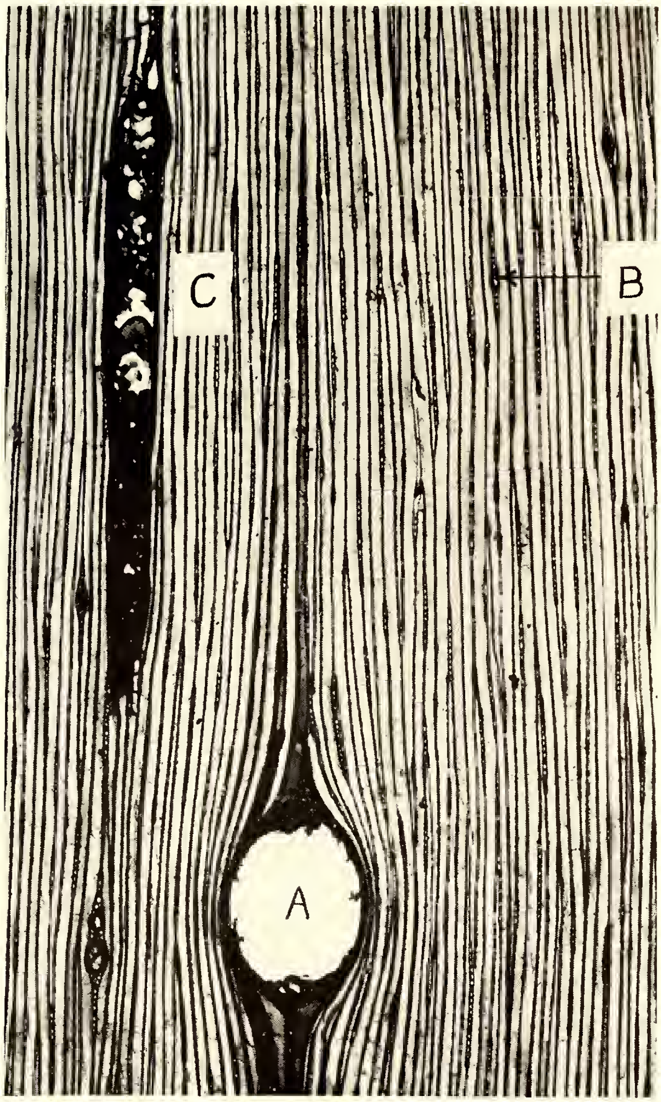

FIGURE 2–81.—Giant resin canals in spruce as seen under the microscope at 40X on a tangential face: *A*, giant radial canal, with large radial canal beside it at left; *B*, normal radial resin canal; *C*, large vertical canal.

2.317. Black Streak and Soot Pockets in Yellowpoplar. Black streak (sometimes called fire streak) and soot pockets are defects peculiar to yellowpoplar that are usually associated. The trouble originates at an injury, leaving a small area where the wood is not intergrown and which is lined with a dry, jet-black material.

Figure 2–83, *A* and *B*, shows the typical appearance of this defect on edge grain and end grain, respectively. Figure 2–83, *C*, is an edge-grain sample from which

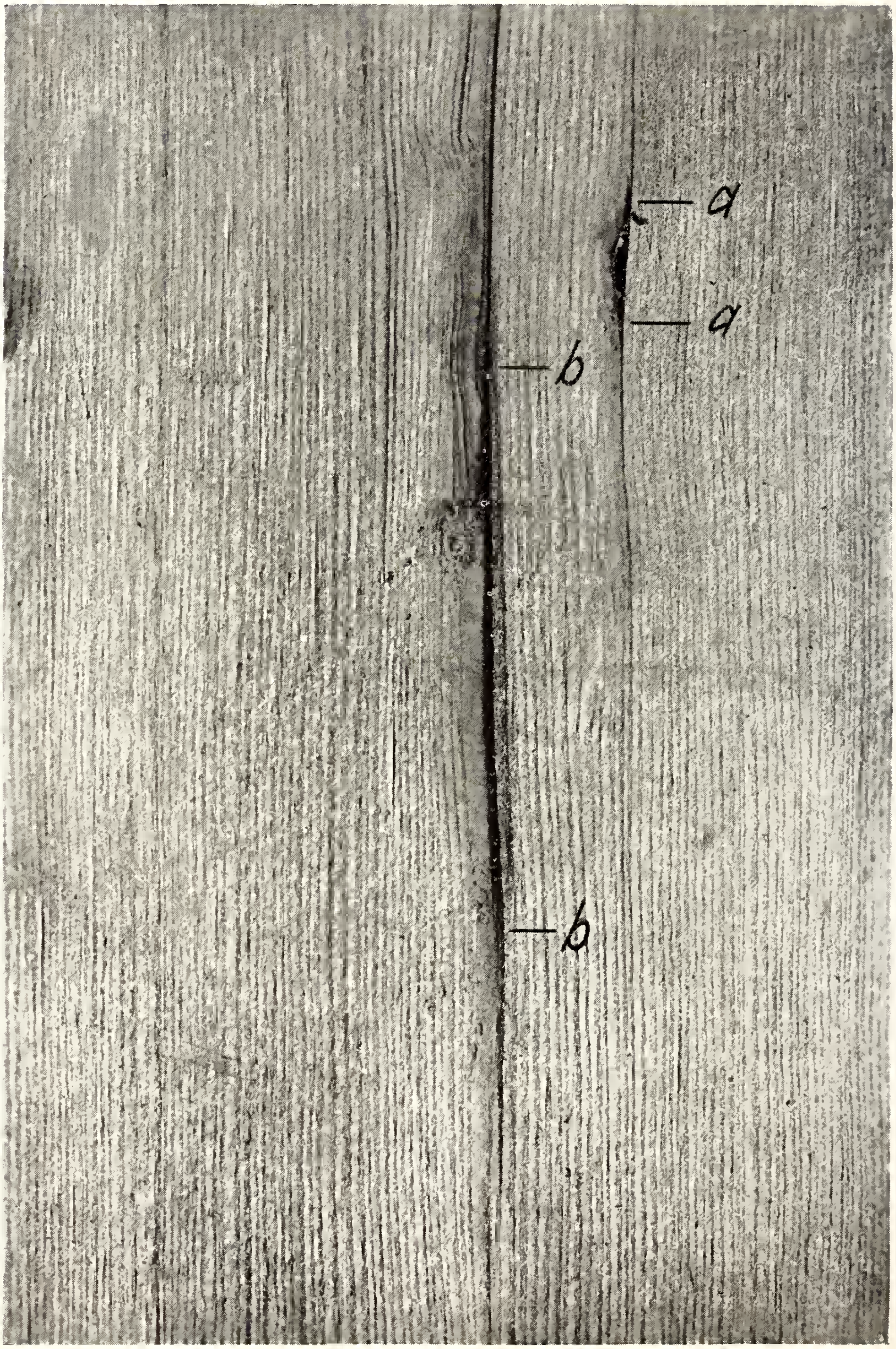

FIGURE 2-82.—Black streak in western hemlock; a–a, and b–b are lengths of the maggot chambers.

the wood at the lower side of the soot pocket has been cut away to show the extent of the area where the annual rings are not intergrown. Figure 2–83, *D*, is a sample of rotary-cut veneer showing the soot pocket in the center, with the black streak or fire streak extending along the grain in both directions.

2.318. Bird Peck. Occasional logs are encountered in yellowpoplar that have been repeatedly damaged by birds, which drill series of holes through the bark into the sapwood. In the great majority of cases, the injuries are shallow enough to heal; the small, rounded spots remaining contain deviations from straight grain that are usually much less pronounced than those in burls. Usually these bird pecks are more or less sparsely scattered over a sheet of veneer; but in extreme cases, as shown in figure 2–84, there may be 100 or more to a square foot.

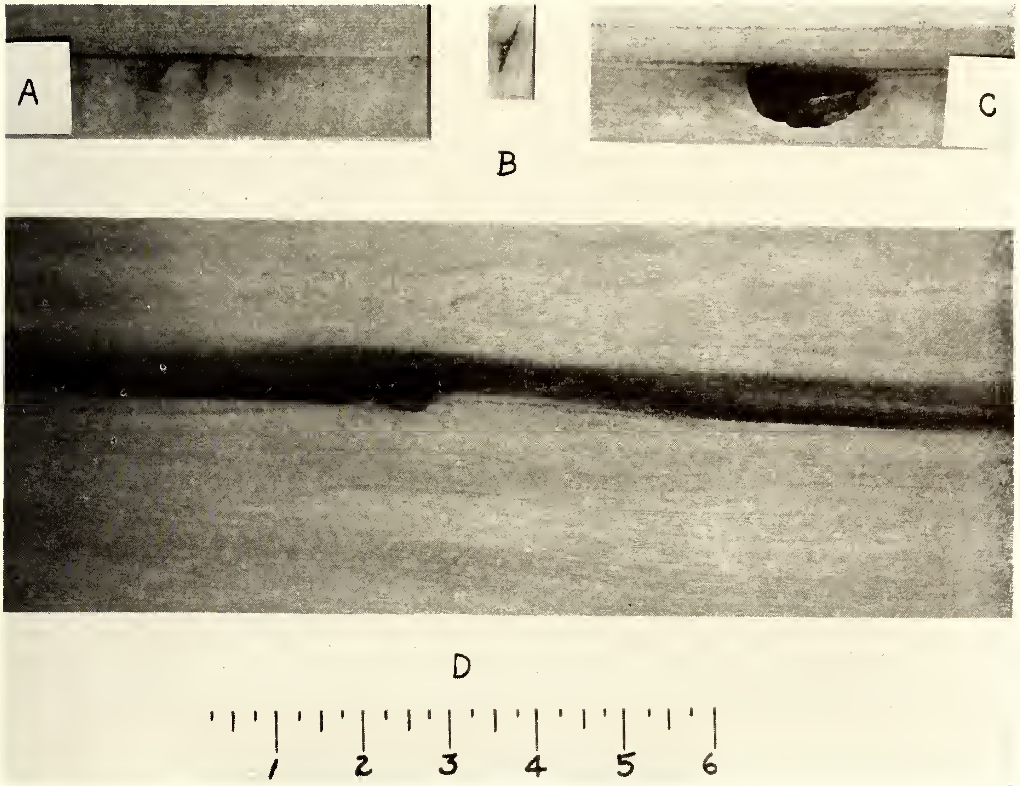

FIGURE 2–83.—Black streak and soot pockets in yellowpoplar.

2.319. Floccosoids in Western Hemlock. Otherwise acceptable western hemlock material is sometimes rejected by inspectors who mistake floccosoids, which appear as white spots or streaks, for decay or dote. Figure 2–85, *A* and *B*, show the appearance of floccosoids. These whitish deposits in the cavities of the wood cells result from the life processes of the tree. They may be nearly formless, granular, or crystalline.

Floccosoids are soluble in various solvents, including such caustic alkalis as potassium hydroxide or ordinary household lye. They dissolve best when paper-thin slices of the wood containing them are submerged in an alkaline solution so that the solution is in direct contact with the deposit. This solubility test may be used to distinguish floccosoids from decay, since under such treatment the floccosoids

FIGURE 2-84.—Bird peck in yellowpoplar.

will disappear but any white decay spots present will not. Also, the floccosoids are at least as firm and solid as normal springwood, whereas decayed spots are softer than normal wood; thus, they can be distinguished by picking at them with a knife blade.

2.320. Veneer Defects. Most of the defects discussed in preceding pages are common to both lumber and veneer. There are, however, certain defects of manufacture that are peculiar to veneer and that require special mention.

2.3201. Rough Cutting. Rough cutting weakens veneer because it usually causes some tearing of the surface fibers. This results in thin spots that can be detected in thin veneer by holding the sheet to a source of light.

Rough cutting also prevents a uniform glue bond, because it is not possible to obtain as close and complete a contact between the glued surfaces as is desirable.

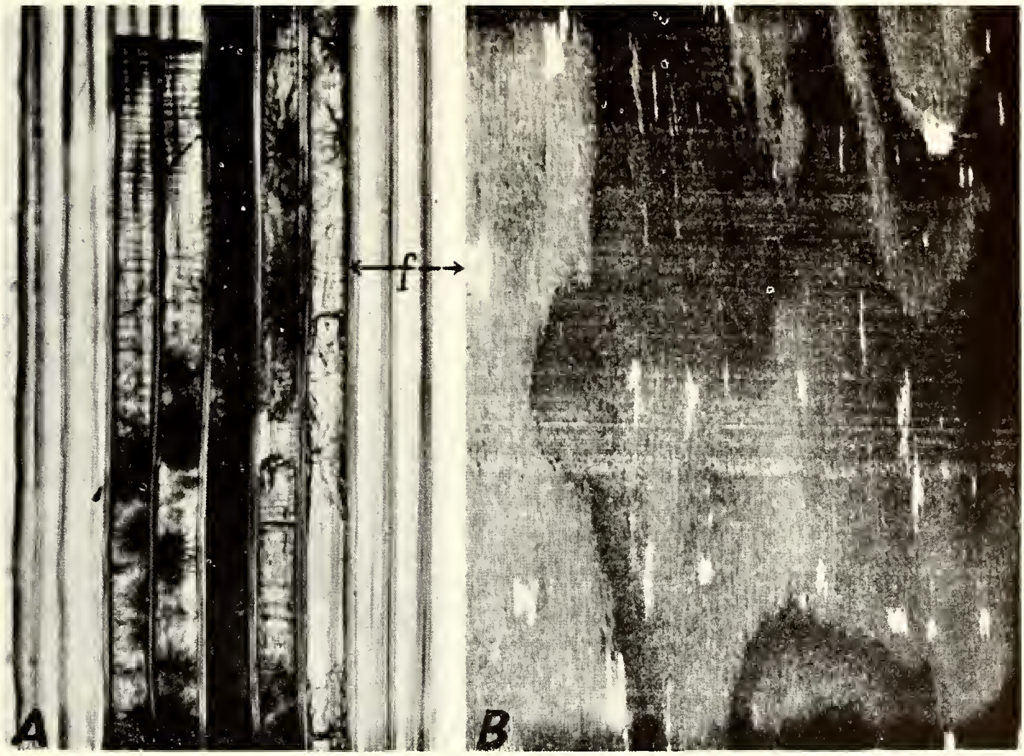

FIGURE 2-85.—Floccosoids—white spots in western hemlock. *A*, Floccosoids (*f*) as seen through the microscope (about 200 × magnification); *B*, floccosoids (*f*) in rotary-cut veneer.

Smoothness of cut is judged by feel and by appearance. Light shining obliquely on one side of a piece makes roughness more evident than does diffused light. Long experience is not needed to detect the more serious types of rough cutting. Assuming that the lathe or slicer is in good condition and well operated, rough cutting is not a serious problem in straight-grained wood. It should, however, be looked for in sheets of veneer that show irregularities of grain resulting from bumps, burls, curl, or interlocked grain. The seriousness of rough cutting from the aircraft veneer standpoint depends on the degree of roughness and the size of the area affected. A very small area that is only slightly rough need not be considered cause for rejecting a sheet that is otherwise of good quality. Figure 2–86 illustrates an objectionable and unnecessary degree of rough cutting in relatively straight-grained hard maple.

FIGURE 2-86.—Objectionable rough cutting in maple.

2.3202. Loose Cutting. Every sheet of rotary-cut veneer has a "tight side" and an "open side." The tight side is that which is toward the outside of the log, and the open side is that which is toward the center of the log. In plywood, the tight side of the surface plies should be the exposed side. Since rotary-cut veneer is cut from the circumference of a circle, the outside is in compression and the inside in tension when the sheet is flattened, as in drying and shipment. In poorly cut veneer, the open side often reveals numerous small surface checks which run parallel to the grain when the sheet is bent so that the open side is on the convex side. In properly made rotary-cut veneer, the difference between the two sides can be detected although the difference is not very pronounced. Sliced veneer may also be loosely cut, especially if the machine is not properly adjusted. Tightness of cut is better in thin veneers than in thick, and, fortunately from this standpoint, aircraft veneers are as a rule relatively thin and therefore relatively tight.

2.3203. Nonuniform Thickness. Well-made veneer should meet certain thickness requirements.

1. It should, on the average, be up to the thickness specified, rather than, as often happens, slightly under.
2. It should be cut with sufficient accuracy to keep within the specified thickness tolerance, ± 0.002 inch or more, according to the thickness of the veneer.
3. The thickness of individual sheets of veneer should not vary more than ± 0.002 inch in different places.

Tests indicate that, with a good lathe properly operated, there is no serious difficulty in meeting there requirements.

2.3204. Lack of Flatness. Sheets of veneer often dry with a wavy, uneven surface, particularly if they are wide or contain areas of cross grain, which cause uneven shrinkage. Such sheets are likely to cause some difficulty in gluing and have a tendency to split in pressing for crating, especially if too dry. Flatness of the best commercial standards is desirable in all aircraft work, but particularly in molded parts. Wavy veneers can be easily squeezed flat in a standard press and uniformly bonded to adjoining layers. In bag and other types of fluid pressure molding, pressures used are lower, and for such purposes the veneer must be relatively flat if a good and uniform glue bond is to be achieved.

2.3205. Frequency of Common Natural Defects in Veneer. Table 2–12 shows the chief natural defects and blemishes found in four common aircraft-veneer woods. The rotary veneers on which these figures were based were cut for aircraft, but actually about one-third were somewhat under aircraft standards by reason of excessive cross grain or other defects exceeding the specifications. The percentages of clear sheets in the veneer inspected were: Yellowpoplar, 25; sweetgum, 53; hard maple, 18; and yellow birch, 41.

Burls were much the most common defect found in yellow poplar, occurring typically as cross sections of buds which were frequently grouped. Single burls seldom exceeded the allowable limit, but their combined diameter or number often exceeded the allowable limit. Burls were sometimes accompanied by rough cutting in the surrounding wood.

TABLE 2–12.—*Frequency of principal natural defects and blemishes found in veneers of four common aircraft woods*

Defect or blemish	Percent of veneer sheets in which defects were found			
	Yellow-poplar	Sweetgum	Hard maple	Yellow birch
Knots	27	29	4	16
Burls	45	5	4	14
Mineral streaks	8	3	27	10
Excessive spiral grain	7	20	6	13
Excessive short grain	6	5	17	9
Excessive curly grain			4	12
Bark pockets	7	2	1	2
Scars	6	1	3	3
Bird's-eye			12	2
Bird peck	5	1	3	1
Worm holes	1	6		

The high frequency of knots in sweetgum is accounted for by the fact that very small ones, one-eighth inch or less in diameter, are fairly common; sometimes several appear in one veneer sheet. Knots in all the woods were, in general, small, sound, and tight.

By far the greatest number of mineral streaks were found in maple, although in the quality of veneer examined they were small and sound. In maple, mineral streaks often check during drying.

For use in aircraft, the most serious defect in otherwise good veneer is cross grain. In small samples, cross grain sometimes reduces the tensile strength to one-third that of straight-grained veneer; and in bending, small cross-grained pieces break at about twice as large a radius as do straight-grained pieces. Cross-grained sheets of veneer do not dry so flat as straight-grained sheets. Where cross grain is extreme, greater difficulties in gluing and finishing are encountered than with straight-grained veneer, because such cross grain in effect is similar to end grain.

The cross grain shown is all excessive cross grain; that is, more extreme than the specifications permit. Only excessive cross grain is recorded here, because every piece of veneer has cross grain in some degree; hence, most of it is not significant. The situation is different with the other defects and blemishes, because they are as a rule entirely lacking in a great majority of the veneer sheets.

No sheet of veneer is perfectly straight-grained. Crook, taper, swell butt, ridges, and bumps prevent many logs from being even closely cylindrical. Curly, spiral, and interlocked grain affect other logs, so that the term "straight-grained" is purely relative. For all practical purposes, this term may be taken to mean that the grain is straight enough to meet specifications.

The sweetgum tree is characterized by a great deal of interlocked grain. It is not surprising, therefore, that the sweetgum veneer examined had more spiral grain than did the other woods. Spiral grain is common in birch also, both in the tree and in veneer, but is less of a problem in yellowpoplar and maple.

Most of the excessive short grain in maple consisted of swirls, or patches of localized steep short grain, that are probably cross sections of sizable bumps or swells on the log. Swirls usually have a slope steeper than 1 in 10; and, since several swirls often occur in one piece, their combined area may well exceed 10 percent of the sheet. In the other woods, the short grain was more often the result of swell butt or crook in the log.

Cross grain resulting from butt swell may be found in almost any wood. The characteristic appearance is shown in figure 2–87. Short grain varying from 1 in 5 up to 1 in 10 is often found in such areas, the steeper slopes being found as a rule where the growth rings are most closely crowded together. This kind of short grain is usually limited to a small area near one end of the sheet, and frequently such a sheet can be greatly improved if shortened a foot or so. Short grain of the same general type can sometimes be found at both ends of a sheet of veneer from a log that has a considerable degree of sweep or crook.

Curly grain was of no great practical significance in the veneer examined, except in yellow birch, about half of the logs of which contained it in varying degree. Only 12 percent of the sheets, however, had excessive curly grain; that is, grain with a slope steeper than 1 in 10 covering more than 10 percent of the surface. Curly grain is often accompanied by rough cutting, which in itself is objectionable. Figure 2–88 illustrates curly grain in birch.

Such irregularities as bumps, burls, swells, and knots are occasionally found in all woods and cause short grain in varying degrees. In figure 2–89, for instance, the steepest short grain in the section through the small bump is 1 in 3, but the area affected is very small in proportion to the size of the sheet. Short grain of 1 in 6 is the steepest found around the section through the large bump in the center of the sample, but the area concerned is much larger.

Figure 2–90 illustrates with khaya ("African mahogany") a type of short grain that occurs in woods having interlocked grain. The two narrower samples are quarter-sliced "ribbon grain," the figure being due to interlocked grain such as often occurs in sweetgum, tupelo, and sycamore. The other two samples are unfigured and plain sliced. Much of the area of some ribbon-grain pieces has slope of grain steeper than 1 in 10, but the unfigured type is typically much more straight-grained.

These typical examples are given, not because they necessarily justify rejection of a sheet, but because they are usually grounds for suspicion and may call for checking. The quality of the remainder of the sheet often determines the acceptability.

2.3206. Measurement of Slope of Grain in Veneer. The slope of grain in veneer is determined with respect to an edge—that is, in the plane of the sheet; and with respect to the face—that is, through the sheet. In rotary-cut veneer, the face is practically a tangential surface; and in quarter-sliced veneer it is approximately a radial surface; in flat-sliced veneer, however, it may vary from tangential to nearly radial even in the same piece.

The slope of grain with respect to the edge in rotary-cut and flat-sliced veneer is indicated by the direction in which the veneer tears or by pores, resin ducts, the direction in which free-flowing ink or dye spreads, or the scribe test on the surface, although in veneer less than one forty-eighth inch in thickness the scribe test is not practical. It is also indicated roughly by elongated mineral streaks and pitch streaks, since they usually extend along the grain, and by the direction in which the apexes of successive annual rings line up on its surface if diagonal grain is present but spiral grain is not present, as illustrated in figure 2–91. If spiral grain is present the grain will take a different course than the apexes of the annual rings, as illustrated in figure 2–92, and therefore the annual rings cannot be relied upon entirely for determining the direction of grain in such veneer.

In quarter-sliced veneer the annual rings indicate the slope of grain with respect to the edge, the same as on radial surfaces of lumber (sec. 2.302), except in khaya, which has no definite growth rings but has sufficiently distinct pores to indicate the direction of grain. If the annual rings are not distinctly visible on the faces of quarter-sliced veneer, as may occur in sweetgum, yellowpoplar, magnolia, water tupelo, and basswood, they sometimes can be seen more clearly by tilting the veneer at a different angle with respect to the light source or the eye.

FIGURE 2-87.—Cross grain resulting from butt swell in yellow birch.

FIGURE 2-88.—Curly grain in yellow birch.

FIGURE 2-89.—Cross grain resulting from small and large bumps.

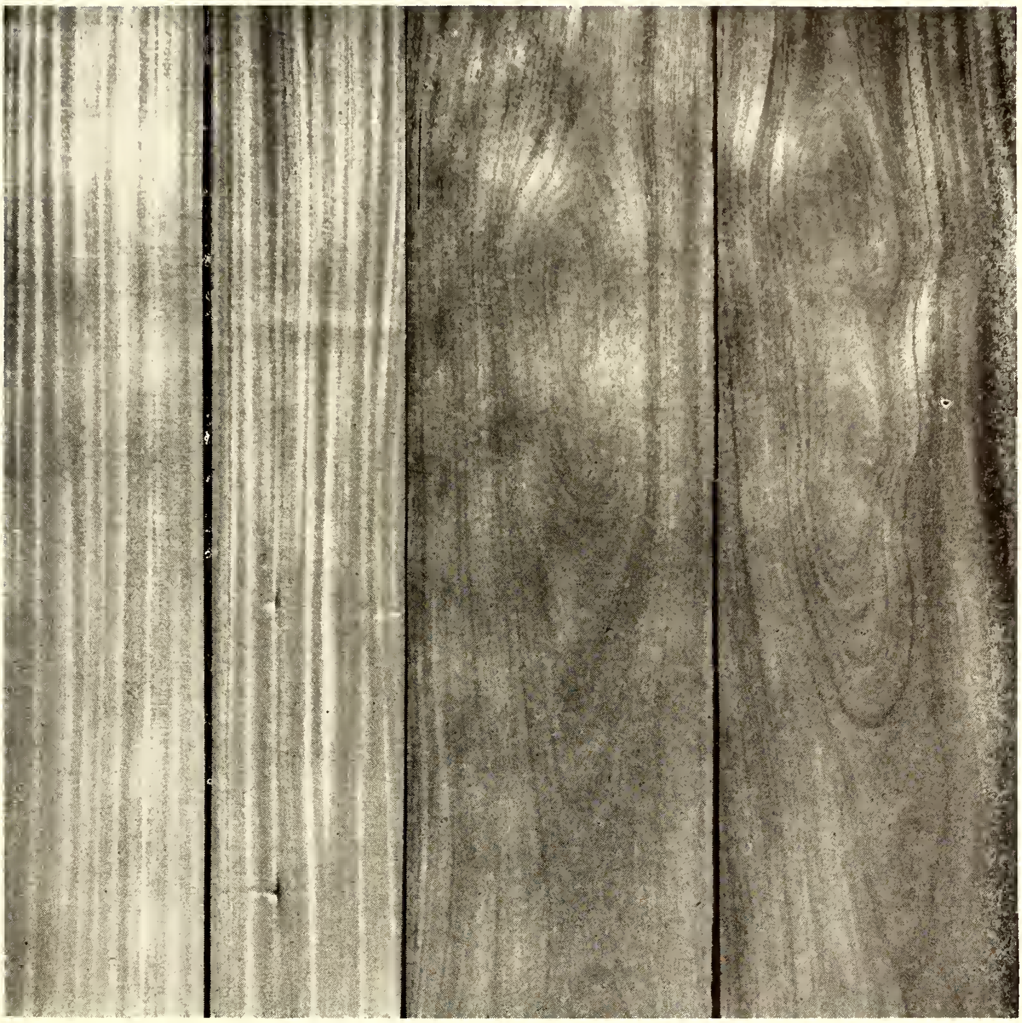

FIGURE 2-90.—Cross grain resulting from interlocked grain.

FIGURE 2-91.—Artifical spiral grain as indicated by oblique alinement of apexes of annual rings on the tangential surface (when diagonal grain is present). Natural spiral grain absent, as indicated by parallelism of split with alinement of apexes of annual rings.

Tearing quarter-sliced veneer to determine the direction of grain may be misleading. If the tearing is done by pulling downward with one hand and upward with the other, the tear may follow the grain (annual rings in this case); but if the reverse motion is employed, the tear may go diagonally across the rings (fig. 2–93, *A*). The difference in tear is due to the radial checks that are formed on the "open" side in such veneer during cutting. These checks are arranged in a diagonal direction across the sheet, because when flitches are placed in the slicer in an inclined position, the knife passes diagonally through the flitch.

FIGURE 2–92.—Natural spiral grain as indicated by split which is not parallel with alinement of apexes of annual rings due to diagonal grain. Compare with figure 2–91.

The slope of grain with respect to the face, or through the sheet, often is more difficult to determine. In rotary-cut and flat-sliced veneer, the presence of numerous parabolas formed by the intersection of annual rings with the surface indicates diagonal grain through the sheet, as in figures 2–91 and 2–92. The ratio of the thickness of the veneer to the length in which the boundary of the same annual ring

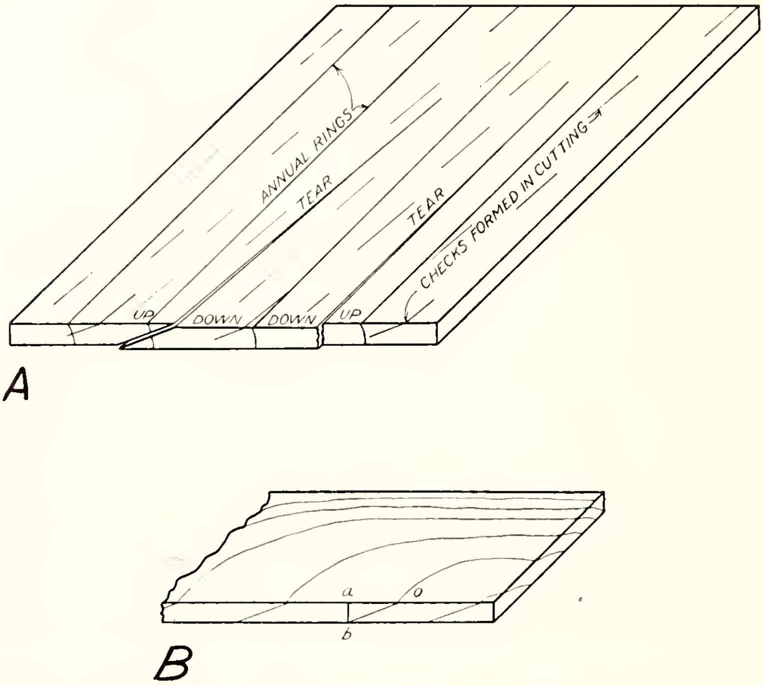

FIGURE 2-93.—*A*, Effect of checks formed in cutting on direction of tear in quarter-sliced veneer. *B*, Method of measuring slope of grain through a sheet of veneer. The line *bo* represents the direction of the grain through the sheet as indicated by annual rings, pores, fibers, fracture, etc. The line *ab* represents the thickness of the veneer. Slope of grain equals *ab*/*ao*.

FIGURE 2-94.—Mycelium on oak and the characteristic cracking of typical brown rot.

intersects the two surfaces is a measure of the slope of grain, as *ab* to *ao* in figure 2–93, in which *bo* is the boundary of an annual ring, although the veneer need not be cut through the apexes of the parabolas, as illustrated, in order to make the measurements. The same annual ring can be identified on the two surfaces by holding thin veneer against a strong light or by pinpricks through the veneer.

A more complete discussion of determining the slope of grain is given in Forest Products Laboratory Mimeograph No. 1585.

In any cut of veneer, the length of resin ducts or of plainly visible pores also is a measure of the slope of grain. For example, if the length of the pores on the surface of mahogany is less than 0.11 inch, in birch 0.09 inch, and the resin ducts in Sitka spruce and Douglas-fir 0.04 inch, the slope of grain is greater than 1 in 10. Strictly speaking, resin ducts in spruce, Douglas-fir, and larch should be measured for length on tangential surfaces only, since, on radial surfaces, several in a row may intersect the surface and make the measurement of single ones unpractical. If a slope of 1 in 10 or greater is present through the sheet, a strip of the veneer when bent until it breaks will show a fracture along the grain unless it was brittle or contained other defects that caused the direction of the fracture to deviate from parallelism with the fibers. The ratio of the thickness of the veneer to the length of the fracture (if it followed the grain all the way through the sheet) measured parallel with the surface is an approximate measure of the slope of grain.

The slope of grain through the sheet also can be measured on the edge by the slope of annual rings, pores, or the fibers themselves when magnified. To do this it may be desirable to clamp the veneer between two pieces of wood with the edges flush and then draw a line parallel with the direction of the grain through the sheet on the edge of the veneer and adjoining pieces of wood so as to facilitate measurement.

Veneer, like lumber, may have the grain sloping with respect to the edge and with the face, in which event the combined slope is the square root of the sum of the squares of the two slopes as explained in section 2.3022.

2.321. Stains and Decays.[2] Many stains, as well as all forms of decay, are caused by fungi that grow on and in wood. Fungi are plants made up of fine threads (hyphae) invisible to the naked eye unless they are massed or matted together. A mass of hyphae is called mycelium. Figure 2–94 shows mycelium on oak and the characteristic cracking in typical decay of a brown-rot type.

The fruiting bodies of the fungi causing either sap stain or decay may appear on the surface of the wood. They vary in size from so small as to be invisible to the naked eye, except in a mass, to quite large and conspicuous. The fruiting bodies of the staining organisms are always small. Those of wood-destroying fungi may be very large and are called conks, brackets, mushrooms, toadstools, and the like. Since they are not formed until the hyphae have developed vigorously inside the wood, their presence indicates serious decay.

The fruiting bodies bear spores, which are microscopically small reproductive bodies of relatively simple structure, analogous to seeds. The spores, being very light, are borne about by air currents. If the temperature and moisture are favorable, they germinate and if they are in contact with wood that is not fungus-resistant they start new centers of decay or stain.

Fungi will grow in wood only if both air and water are present, and at temperatures varying from 35° to 100° F. These requirements vary widely with different fungi.

Lumber with a moisture content of less than 20 percent will not stain or decay. The most efficient method of preventing stain and decay is to kiln dry lumber before it becomes infected. The temperatures used in kiln drying are usually sufficiently high to kill any organisms that might be present in the wood. It is difficult to air

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[2] This section was prepared by the Division of Forest Pathology, Bureau of Plant Industry, Soils, and Agricultural Engineering, U.S. Department of Agriculture, which is maintained at Madison, Wis., in cooperation with the Forest Products Laboratory.

dry lumber quickly enough to prevent infection. Therefore if the lumber is not to be kiln dried immediately, and especially if it is to be shipped before seasoning, it should be given added protection by dipping in one of the several antistain chemicals now in use (*2–4, 2–6*).[3]

In finished aircraft or aircraft parts decay will neither start nor progress if they are kept dry (*2–2*). In design and construction there should be no unnecessary openings through which water can enter. Protection is needed particularly against rain, splash from wet fields, and water used in washing. Openings at inspection plates, pitot tubes, gasoline gages, and the like, should be made tight by gaskets or otherwise. On some models, joints, such as that between wing and center section, or between vertical and horizontal stabilizers, need special attention to closure by tight fairing strips or otherwise. Ailerons should not have exposed lightening holes at their ends. Openings through which pedal rods or control cables pass into structural members are safer if protected by boots.

Construction should be such that any water that does get in cannot accumulate or remain in any part. Properly placed drain holes are essential for preventing decay of aircraft in use. Drainage holes should be at the lowest points. At trailing edges of wings and ailerons, decay commonly develops if the drains are 2 or 3 inches in front of the trailing-edge strip; they should be at the edge, and where metal trailing edges are used the drains should be in the metal itself. In fabric-covered airplanes care is needed to punch the holes cleanly to provide the ¼-inch opening that is needed. Drains so placed that water and dirt can get into them during landings made on wet fields can be protected by marine grommets. Perhaps some of the fins or other thin members can be entirely sealed, but the safety of omitting drains cannot be judged until the possible importance of internal moisture condensation has been more thoroughly studied.

An added safeguard against decay at trailing edges would be to make the trailing-edge strip from heartwood of one of the more decay-resistant species. Impregnation of aircraft parts with chemical preservatives is not compatible with present gluing techniques, and the surface treatments with preservatives are of such limited effectiveness that their use does not justify any slackness in provision for keeping wood dry.

In shipping or storing aircraft and aircraft parts the greatest care should be taken to prevent water getting into the crates. It is safest to unpack crated airplanes and parts as soon as practicable after receipt; if parts must be stored where there is any chance for water to reach them, they should be placed with openings downward so that water will run out rather than in. Lack of air circulation, combined with high atmospheric humidity and temperature, affords a favorable condition for the growth of wood-inhabiting fungi.

2.3210. Occurrence of Staining Fungi. Wood may stain at any time after the trees are felled so long as the moisture content remains favorable for the growth of the fungi. Staining fungi normally limit their activities to moist sapwood; probably the heartwood is not suitable for their development. Most discolorations caused by molds and by the early stages of staining fungi may be planed off, but both molds and staining fungi may penetrate deeply in the wood in a few days. In general they do not materially affect the strength of the wood, but in very bad cases the toughness may be reduced (*2–3*). Fungus stains are generally caused by the color of the fungus threads as seen through the cell walls of the wood, although in some cases soluble pigments excreted by the fungus actually stain the wood. The colors generally vary from steel gray to bluish black, but yellows, reds, and browns sometimes occur. The hyphae are frequently concentrated in the rays.

2.3211. Stains in Conifers. Among the conifers or softwoods, spruce, sugar pine, western white pine, ponderosa pine, and southern yellow pine are very subject

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[3] Italic numbers in parentheses refer to references given at end of section.

to sap stain, especially blue stain. Noble fir and cedar are not so commonly affected. Douglas-fir and western hemlock are intermediate.

(a) Blue stain (*Ceratostomella* spp. and other fungi): Figure 2–95 shows blue-stained pine sapwood. This appearance is typical of blue stain at a well-developed stage in the conifers. As the stain develops, the entire sapwood becomes dark blue gray and may become almost black. At this stage the toughness of the wood may be considerably reduced.

A limited amount of blue stain sometimes occurs in the heartwood of Sitka spruce and the cedars. It should not be confused with the diffuse bluish or purplish-gray discoloration that occurs in the outer heartwood of noble fir. The latter seems to be accentuated by an oxidation that takes place after the timber is cut. A similar discoloration frequently occurs in Douglas-fir, marking the outer margin of an area infected with a wood-decaying fungus.

FIGURE 2–95.—Planed southern yellow pine board showing typical sap stain.

(b) Red stain in Sitka spruce: Besides blue stain, a spotty red stain is sometimes found on both the sapwood and heartwood of Sitka spruce airplane lumber (*2–1*). On the rough lumber the stain appears as terra cotta or brick-red spots, varying from a very faint to a pronounced color. It is superficial, usually surfacing off during manufacture. This red stain does not mar the appearance of Sitka spruce to the same extent as blue stain. So far as is known, the strength of the wood is not reduced by the unidentified fungus causing this discoloration.

A similar reddish stain frequently occurs on the surface of western hemlock heartwood. This stain, however, diffuses over the surface. It is not caused by fungus action but seems to be the result of an oxidation of some of the extractives in the wood that occurs during slow drying. This stain is generally superficial, extending no deeper than about a sixteenth of an inch, and would be planed off in manufacturing.

(c) Brown stains: Chemical brown stains occur during either air seasoning or kiln drying. These stains may occur as yellow to dark-brown discolorations and are most noticeable in the sapwood and heartwood of sugar, ponderosa, eastern white, and occasionally western white pines. The brown stain occurring during kiln drying is of a chemical nature. Brown stain occurring during air seasoning may be caused by fungi. The cause of the chemical brown stains is not known, but they seem to result from the deposition and oxidation of extractive materials as the moisture of the wood is evaporated. When chemical brown stain occurs it is frequently just below the surface of the boards and is therefore seldom detected until after planing.

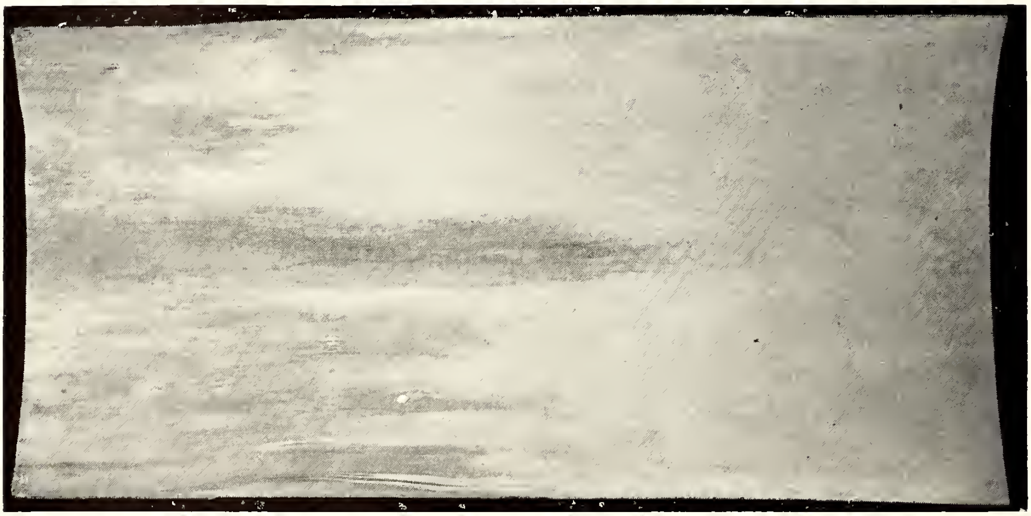

FIGURE 2-96.—Sap stain in sweetgum veneer. The stain originated in a log that had lain too long on the ground.

During drying Sitka spruce may become spotted so that the planed wood has the appearance of being blotched with "grease spots." These spots are shallow and should not affect the wood. In western hemlock and noble fir deposits form at or near the surface of the boards so that when they are planed they have a dark streaked appearance. Deeper planing usually removes such discolorations.

The surface of western hemlock and noble fir boards frequently becomes brick red during seasoning. The color is superficial and should plane off. This is not caused by fungus infection, but seems to be caused by some oxidation. The stain develops as a result of exposure of unseasoned wood to the air.

2.3212. Stains in Hardwoods. (a) Blue or brown stain (*Ceratostomella* spp. and other fungi): Stain in the hardwoods is caused by fungi similar to or identical with those attacking softwoods. Of the hardwoods, sweetgum is the most susceptible to sap stain. Sweetgum and yellowpoplar logs frequently become stained by the fungus growing in from the ends (fig. 2-96). Unless logs are to be sawed within a short time the freshly cut ends should therefore be treated to prevent the growth of the staining fungi (*2-6*, *2-10*). The stain may extend entirely through the sapwood. It is easily recognized after once being seen and is not likely to be confused with decay. In general, stain is often most intense in the wood rays and larger pores or vessels. In a wood, such as yellow birch, in which the vessels are not closely crowded, the stain, if not too severe, appears in longitudinal sections as very narrow bluish-black lines or streaks following the grain of the wood.

(b) Yellow stain: A yellow stain caused by *Penicillium divaricatum* is often present in oak lumber. It is detected most easily on freshly surfaced wood. The yellow color apparently is caused, at least in part, by the dyeing of the wood by a water-soluble substance produced by the fungus. If the fungus works sufficiently long the board will become yellowed throughout. Lumber seasoned without delay after it is cut and then stored in a dry place should not become stained, but added protection may be given by dipping or spraying the lumber with an antistain chemical.

The more or less general yellowing of the surface of some air-dried yellow-poplar lumber seems to be caused by chemical action, not by a fungus. The yellow is, in most cases, more intense at the end of the growth ring and usually does not extend into the wood more than a sixteenth of an inch. It is not known to affect the strength. It may, however, be confused with decay, since many yellowpoplar decays are straw-colored or brownish. Thus, where yellow discoloration of the sapwood appears after surfacing, the wood should not be used in stressed members, on suspicion of decay.

2.3213. Occurrence of Wood-decaying Fungi. Some fungi consume the cell walls causing decay of the wood. Even in the early stages of decay the strength of wood may be considerably reduced (*2–11*). In living trees the wood-decaying fungi usually confine their activities to the heartwood. After the trees are felled, however, the so-called storage rots attack the sapwood first, as a rule, and later may spread to the heartwood. All sapwood is susceptible to fungus deterioration, but the decay resistance of the heartwood varies considerably with the kind of wood. Since all aircraft lumber should be so handled that fungus infection does not take place, the discussion here is most concerned with the infections that might be present when the lumber is cut.

2.3214. Detection of Decay. It is usually a simple matter to recognize well-advanced rot or typical decay where the changes in wood structure are caused by prolonged action of the wood-destroying fungus. The early stages of decay are, however, far from easy to recognize. In some cases detection is practically impossible without a microscopical examination of the wood.

Incipient decay usually appears as a discoloration, in some cases pronounced, in others so faint as to be practically invisible. It rarely ends abruptly or evenly, but usually fades out in one or more irregular streaks. Such streaks usually extend not more than 3 or 4 feet, measured along the grain of the wood, beyond the typical decay. In softwoods the discoloration due to decay as observed on a cross section may be distinguished from the normally darker bands of heartwood by observing whether or not the darkening follows closely a definite group of annual rings. If so, the color variation is probably normal; if, on the contrary, the discoloration pattern is independent of the ring pattern, the color change may be a symptom of decay.

Incipient decay should be, and usually is, rejected at the sawmill. It is more easily detected in the original board because it is ordinarily connected at one end with well-developed and recognizable decay, and also because, when the lumber is green, the discolorations indicating incipient decay are more intense than after the wood has been seasoned or exposed to the light for some time. A drastic rejection policy at the trimmer is the most effective safeguard. The distance to which apparently sound wood must be rejected because of adjacent decay is usually very short in the radial direction, somewhat greater in the tangential, and varies in the longitudinal direction from a few inches in most hardwood rots to as much as a dozen feet for a few fungi in conifers (*2–1*).

In inspection at later stages of grading and manufacture, safe judgment depends first on thorough acquaintance with the appearance of normal wood of the species being inspected. The so-called pick test, which depends on the pressure required to force a sharp point into the wood or to turn up a splinter with it, or on the character of the splinter that is turned up, is as commonly employed for detecting brashness caused by fungi as it is for brashness due to other causes, and is believed helpful by many expert graders. However, it has sometimes caused much unnecessary rejection, and neither this nor any other known test that can be used by an inspector is a substitute for the expert knowledge of a species that is acquired by experience. Some types of decays are described in the following paragraphs.

2.3215. Decay Developed in Standing Trees. 1. *Conifers.*—(a) Ring-scale fungus (*Fomes pini*): One of the commonest decays in airplane lumber is that caused by the ring-scale fungus in the heartwood of living trees. It is known by various names, such as red rot, red heart, conk rot, white honeycomb rot, pecky wood rot, and ring-scale rot. It may occur in practically any species of conifer (softwood), but is most common in spruce, Douglas-fir, hemlock, fir, and pine. It is readily recognizable in its typical stage by the fact that the heartwood is honeycombed with small white pockets in which the wood is reduced to a soft fibrous mass, the pockets being separated by firm and apparently sound wood. Figure 2–97 shows typical decay of this character in hemlock.

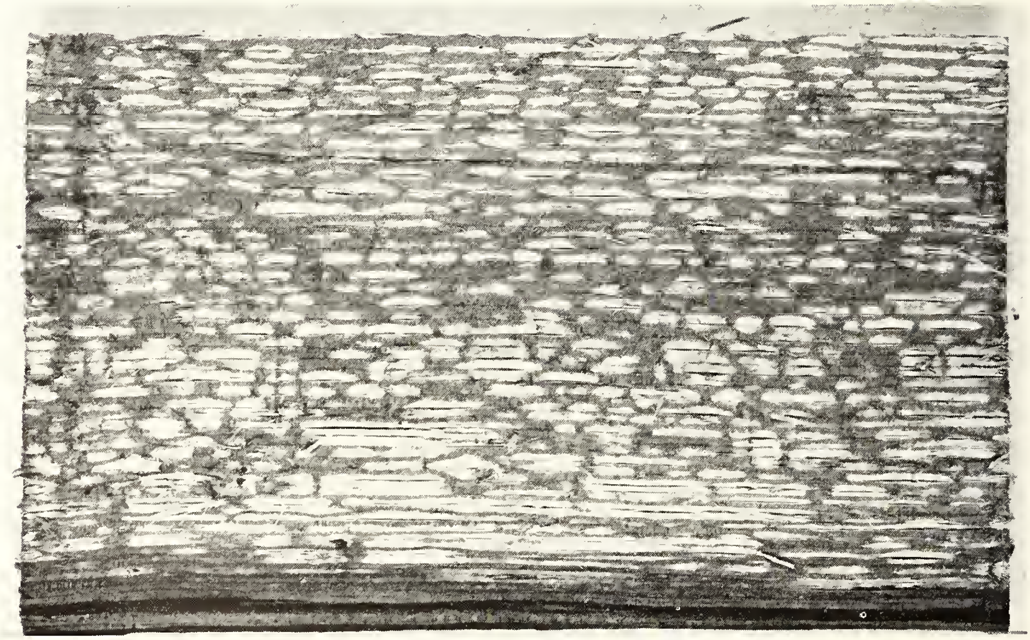

FIGURE 2–97.—Typical pocket rot in hemlock.

While the typical decay has practically the same appearance in various species of wood, there is considerable difference in the incipient decay. In Douglas-fir the incipient decay appears, generally, as a zone of reddish-purple or olive-purple discoloration, gradually tapering and becoming fainter as it follows the grain of the wood until it is lost entirely. The color is often most pronounced in the outermost heartwood, just where it adjoins the sapwood. In some cases it appears brownish against the red or yellow heartwood. Sometimes it is bounded by a narrow zone of pronounced red color. Where the incipient decay begins to merge into typical decay, scrutiny will usually reveal indications of the pockets. Vertically the discoloration may extend 10 feet or more in advance of the pockets, but radially its spread is limited to 2 or 3 inches beyond them.

In white and red spruce the incipient decay of ring-scale fungus first appears as a grayish discoloration in the pale yellowish or reddish brown of the normal heartwood. The grayish discoloration deepens to brown, but it is never so pronounced as in Douglas-fir. Next, the pockets appear, visible at first as tiny black lines following the grain of the wood, but soon revealing their true character. In Sitka spruce the tiny black lines preceding the formation of pockets are not found.

In western hemlock, the incipient decay is indicated by a pink to reddish-purple color. In advanced decay the pockets are spindle shaped. They should not be confused with floccosoids (sec. 2.319). Brown or black threadlike lines are present in badly decayed wood.

The yellow pines first show ring-scale fungus decay by a pronounced pink color, which rapidly gives way to red brown; hence the name red rot and red heart.

In California incense-cedar, Port Orford white-cedar, western redcedar, and probably other cedars, the initial decay produces little or no discoloration. The first indication of a diseased condition of the wood is the appearance of the pockets. Hence there is no reason for mistaking the purplish-red color, normally found in the heartwood of California incense-cedar and western redcedar, for decay.

(b) Chalky quinine fungus (*Fomes laricis*): Chalky quinine fungus causes a pronounced decay in the heartwood of many softwoods. The typical decay is a brownish-red, friable, crumbly mass breaking into cubical fragments and often with conspicuous mycelial felts filling the cracks in the wood. In many cases the incipient decay is accompanied by an extremely faint brownish discoloration that is not discernible to any but the most expert eye, although the wood at this time may be severely weakened. In ponderosa pine, however, the incipient stage can be fairly easily recognized as a red-brown or pronounced brown discoloration in the pale lemon to light orange-brown heartwood. The discoloration is not uniform over the entire portion affected, but may occur on sawn lumber in bands of varying color intensity, sometimes intermingled with narrow bands of the normal heartwood. In cross section the infected wood presents a mottled appearance. The horizontal limits of the discoloration are bounded by a narrow band of pronounced pink or red. At the upper limits of the incipient decay the discoloration becomes fainter until it finally disappears. All the discolored wood, except that in actual process of disintegration, seems to be hard, firm, and strong, but in reality it is seriously weakened.

(c) Velvet-top fungus (*Polyporus schweinitzii*): Velvet-top fungus causes a reddish-brown, crumbly rot breaking into cubical fragments, which is confined to the butt heartwood and the roots of the tree. The mycelial felts are very fine and inconspicuous. As a rule, the incipient decay is very difficult to detect. In Sitka spruce it first becomes evident as pale yellow to lemon yellow streaks or tapering bands. At a later stage the streaks or bands are seen to extend longitudinally beyond a light yellowish-brown to reddish-brown discoloration which characterizes the more advanced attack of the fungus. At this stage a softening of the wood is apparent. In Douglas-fir the incipient decay is first evident as a faint yellowing or browning of the normal heartwood. In western red-cedar, velvet-top fungus infection, or a similar decay, is first indicated by a decided deepening in the color of the normal brownish heartwood, the zone of discoloration extending horizontally for several inches around the typical decay and for a foot or more upward in the tree in advance of it.

(d) Indian paint fungus (*Echinodontium tinctorium*): Indian paint fungus causes a stringy brown rot in the true firs in the western United States, being especially prevalent and severe on white fir. It also occurs in western hemlock.

In white fir the first indications of this decay on a radial or tangential surface are light-brown or golden-tan spots or larger areas of discoloration in the light-colored heartwood, which may be accompanied by small but clearly distinct radial burrows, resembling somewhat very shallow insect burrows without the deposit of excrement. These burrows are not easily detected in cross section. Next, rusty reddish streaks appear following the grain. Throughout this stage the wood may appear in other respects quite normal, but in reality it is so greatly weakened that boards may separate along the annual rings when dried. The discoloration intensifies, the wood becomes soft, showing a decided tendency to separate in the springwood of the annual rings; finally the typical stage is reached, in which the wood is brown, with pronounced rusty reddish streaks and fibrous and stringy texture. Hence the name stringy brown rot is commonly applied to the decay in this typical stage. The incipient decay usually extends from 2 to 6 feet beyond the typical decay.

In western hemlock the incipient decay is much harder to detect, because the initial discoloration, above described, so closely approximates the pale-brown color, slightly tinged with red, of the normal heartwood. The wood first assumes a faint yellowish color, which is sometimes intensified by the presence of small, hardly discernible brownish areas. These areas later develop into the typical decay. The extension of the incipient decay beyond the typical decay varies from 1 to 5 feet.

2.3216. Decay Developed in Standing Trees. 2. *Hardwoods.* — (a) White heart rot fungus (*Fomes fraxinophilus*) attacks the heartwood of living ash trees in the Mississippi valley and produces a very characteristic rot. On cross section the first indication of the decay is a brownish discoloration often difficult to distinguish from the normal grayish brown or reddish brown of the heartwood. The discoloration is most apparent in the broad bands of summerwood. The springwood gradually turns to a straw color and small white spots appear on it. On radial (edge grain) and tangential (flat grain) faces of lumber the spots appear as streaks or blotches, usually following the grain but sometimes at right angles to it if the decay follows a wood ray.

As decay progresses, the whitish color gradually becomes more marked until the entire springwood is affected and appears disintegrated. Then the fibers fall apart. The summerwood passes through the same process, but more slowly, so that in the earlier stages of typical decay the wood has a banded appearance. The completely rotted wood is whitish or straw colored, very soft and spongy.

The white spots are the first visible development of the mycelium of the fungus. Hence, wood with the brown discoloration alone need not necessarily be rejected, but it should be closely scrutinized for more advanced decay. Preferably toughness tests should be made on such material to determine whether it possesses sufficient strength. The incipient decay is somewhat obscured in rough lumber, but is usually easy to recognize on smooth surfaces.

(b) White heart rot of beech, birch, maple, and oak (*Fomes igniarius* and other fungi): The first indication of the incipient decay caused by some white heart rot fungi is a brown discoloration, not very apparent against the reddish-brown heartwood. Next pale streaks appear, which finally turn yellowish white and become plainly evident against the dark background. In the center of the streaks small spots are found in which the yellowish white wood appears to have collapsed. Figure 2–98 shows this rot in rotary-cut veneer. The long axis of the spots is usually parallel to the grain, but in some cases may be at right angles to it. Up to this time the wood, even that which appears collapsed, is fairly firm. Whitish streaks or spots may be found as much as 8 feet in advance of the typical decay. Next the streaks merge, the wood becomes soft, and finally the entire volume of heartwood affected is reduced to a yellowish-white fibrous mass.

(c) White pocket rot of oak (*Polyporus dryophilus* and other fungi): In the unseasoned heartwood of oak the area of incipient decay of this common type of rot has a water-soaked appearance, but when the wood is dry the discoloration becomes light to medium brown in color. The discoloration may extend from 1 to 10 feet in advance of any other indication of the decay. The next stage, which is best seen on an edge-grain face, is characterized by whitish spots or streaks, usually following the wood rays, which produce a mottled appearance of the wood. In the final stages the decayed wood has a white, stringy appearance and, although fairly firm, is worthless as a material of construction.

FIGURE 2-98.—*Fomes igniarius* rot in rotary-cut yellow birch veneer.

(d) Honeycomb heart rot of oak (*Stereum subpileatum*): The first indication of honeycomb heart rot in oak is a slight water-soaked appearance of the fresh heartwood. When the wood is dry this "soak" becomes light brown. Next, isolated bleached areas appear in the discolored wood and within these areas are seen small irregular whitish patches that develop into pockets with their long axes parallel to the grain of the wood. The pockets increase in number until the affected wood is full of them. They are from one thirty-second to one-fourth inch wide by one-fourth to five-eighths inch long and are lined with cottonlike fibers. At this stage the honeycomb heart rot is similar in appearance to the ring-scale fungus decay in conifers, previously described. Later the cottony lining may disappear.

2.3217. Types of Decay in Logs and Lumber. In addition to the wood-destroying fungi that attack living trees, there are fungi that grow only or principally on wood in the form of logs or lumber. Sapwood is soon decayed if kept under moist conditions, but heartwood of some species is very decay resistant. Decay by such fungi is caused by improper handling of the timber during storage, manufacture, or use.

(a) In coniferous logs and lumber, rot is commonly caused by *Lenzites sepiaria*, *L. trabea*, or *Fomes pinicola*. In typical decay the wood is brown and friable. In the early stages of decay, infected wood is darker in color than the normal. Sometimes the early springwood of the annual rings may be completely decayed while the summerwood is scarcely affected. In this condition the wood separates readily along the annual rings.

A brown rot has been encountered in aircraft Sitka spruce lumber. Most frequently the rotted spots are very small, but sometimes they form streaks. The boundary between decayed and sound wood is not sharp. There is a gradual transition from the badly decayed spots to sound wood. The cause of this decay is not known. The incipient stage as seen on the surface of quarter-sawed boards might easily be confused with the "grease spots" described in section 2.3211.

(b) In hardwood logs and lumber certain fungi (*Polyporus versicolor*, *Stereum hirsutum*, and others) cause sap rots that are very difficult to detect in their incipient stages (*2–8*). The first indication of decay is a faint whitening of the diseased wood. The typically decayed wood is white in color, very light in weight, rather soft, and easily broken in the hands. This type of decay is most common in hardwoods, although it occurs to some extent in softwoods. Under proper storage conditions it should not be found at all.

A decay occurs in sweet birch, sweetgum, and yellowpoplar in which the infected wood is light in color with thin black zone lines. The lines are a certain indication that decay has progressed sufficiently to cause considerable weakening even though the wood seems hard and firm. In yellowpoplar the infected wood is frequently pink in color.

2.3218. Variation in Color of Sound Wood. There is considerable variation in the natural color of woods. The causes of such variations are not clearly understood. However, in Sitka spruce reddish streaks frequently occur that have the appearance of being infected with certain fungi. Some of these streaks might be called resin streaks since they generally extend from a resin pocket. Upon close examination it may be seen that the color is caused primarily by deposits in the ray cells. In this way they differ from incipient decay streaks in which the color is not concentrated in the rays.

A purplish gray stain occurs in noble fir. It is typically more intense at the junction of the heartwood and sapwood, but the color frequently extends well into the heartwood. It may be solid or in bands separated by heartwood of lighter color. It is not evidence of decay, and is to be regarded as a normal coloration.

In yellow birch the sapwood may vary from almost white to light orange yellow, and the heartwood may vary from very light yellowish brown to dark reddish brown (*2–5*). In general, uniformity of color over extensive areas, particularly in veneer, may be taken as an indication of normality, but frequently discolorations occur, which in rotary-cut veneer show up as narrow bands of color merging gradually into each other and running parallel to the grain. Predominant shades are greenish brown, olive, yellowish brown, and grayish brown. The colors are not brilliant as they are in the heartwood of yellowpoplar. Such discolored veneer is often fuzzy to velvety but the veneer does not seem to be always infected by fungi. Light streaks occur occasionally in the heartwood. These may be "included sapwood." Figure 2–99 shows such a streak.

The heartwood of sweetgum is frequently highly figured and is either walnut brown or gray brown. Such wood is as strong as plain heartwood (*2–9*).

FIGURE 2–99.—Light streak in the heartwood of yellow birch.

There is a wide variation in the color of yellowpoplar (*2–7*). Good sound heartwood may be a pure yellow-buff or greenish yellow streaked with varying widths of blackish zones or it may vary from pure yellow-buff through many colors, such as yellow, greenish yellow, yellow green, dark green, lavender, purple, purple brown, and red. If the heartwood is white, warm buff, salmon buff, yellowish brown, or brown, decay should be suspected.

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1941. THE EFFECT OF CERTAIN HEART ROT FUNGI ON THE SPECIFIC GRAVITY AND STRENGTH OF SITKA SPRUCE AND DOUGLAS-FIR. U. S. Dept. Agr. Tech. Bul. 779, 24 pp., illus.

2.4. REQUIREMENTS FOR WOOD IN SPECIFIC PARTS.

2.40. General. The amount of perfect lumber of any species in the larger sizes used in aircraft is limited, but greatly increased quantities of suitable material may be obtained by the judicious utilization of smaller sizes through the modern technique of spliced and laminated construction, and by a proper understanding of so-called blemishes and defects as related to strength. The influence of certain blemishes or imperfections is frequently overemphasized, causing unnecessary rejection of suitable material. Futhermore, since the effects of defects depend not only on their character and size, but also on their location in the piece and on the kind and magnitude of stress to which the piece is subjected, it is both possible and practical to admit some defects and to so effect their limitation and placement in finished parts that they do not reduce the strength. The tolerance limitations for blemishes and defects set forth herein are so established as to provide maximum utilization of material without sacrifice of strength. This requires limitation of defects according to the character of the member and the position of the defects in it, and furthermore requires considerable detail in describing the permissible size and location of the defects. The requirements apply in general to parts made from any species of wood, although the several types of defects for which restrictions are provided do not occur in all species and some defects other than those mentioned are found in some species. Admissibility of such defects must be judged on the basis of their equivalence to those permitted. In this connection careful attention should be given to the discussion of defects and their effects as presented in section 2.3.

2.400. Definition of "Lamination." A lamination may consist of a single piece or of two or more pieces edge glued to form the required width or depth. Edge glue lines in adjacent laminations should be staggered not less than the thickness of the thicker lamination (fig. 2–105).

2.401. Requirements for Annual Ring Direction. Requirements for the use of flat-grained or edge-grained material are based on consideration of the stability of dimension and shape and are not specified because of any difference in strength. Edge-grained lumber shrinks and swells less in width than does flat-grained lumber. Consequently, change in the vertical dimension of a spar with changes in moisture content during manufacture and assembly, as well as in service, is minimized by making its vertical face edge-grained. Furthermore, edge-grained material is less subject to cupping and warping than is flat-grained. In general, the use of flat-grained and edge-grained laminations in the same assembly should be avoided.

2.402. Definitions of "Edge-grained" and "Flat-grained." An edge-grained board, part, or lamination is defined as one in which the annual rings make an angle of 45 degrees or more with the wider surfaces; a flat-grained board, part, or lamination is defined as one in which the annual rings make an angle of less than 45 degrees with the wider surfaces. Edge-grained and flat-grained faces or surfaces are similarly defined.

2.41. Requirements Generally Applicable to All Wood Parts. The requirements given herein as being generally applicable to all wood parts should be considered to be in addition to the requirements for specific parts given in later sections unless, in such sections, specific exception is made.

2.410. Slope of Grain.

2.4100. Requirements. In general the slope of grain in any part with respect to the longitudinal axis of the part should be not steeper than 1 in 15. In tapered members subject to nonuniformly distributed tensile stress the slope of grain should be measured with respect to the center line of the face at which the tensile stress is greatest. The slope of grain within the middle half of the depth of solid or laminated spars may be permitted to be as steep as 1 in 10.

2.4101. Local Deviations of Grain Slope. It is obvious that local deviations of grain involving slopes steeper than those permitted will sometimes be permissible. It is difficult to set up definite requirements for permissible local grain deviations which will be valid or applicable to all cases, since the type, magnitude, and location of such deviations vary greatly. Hence, it is essential that inspectors use a certain amount of discretion and judgment relative to material having local grain slopes slightly steeper than the specified values.

A general requirement for solid or laminated spars is that no grain deviation steeper than the specified value of 1 in 15 should be permitted in an outer eighth of the depth of the spar. In an adjacent eighth deviations involving steeper slopes such as a wave in a few growth layers are unlikely to be harmful. Local grain slope deviations in excess of those specified will be permitted in spar flanges only in the inner one-fourth of the flange depth. This applies to both solid flanges, and horizontally or vertically laminated flanges.

2.4102. Combinations of Grain Slope. When a piece has diagonal as well as spiral grain, the effective grain slope will be steeper than either of the two slopes considered individually. This combined slope may be determined as outlined in section 2.3022. References to slope of grain relate to the combined or effective slope and are not to be construed as pertaining to only one or the other of the two types. Spiral grain is difficult to detect, and for this reason much closer inspection is needed than for the detection of diagonal grain. It may be noted (see table 2-11) that for a permissible grain slope of 1 in 15 no consideration need be given to the combined slope when neither the diagonal nor spiral grain has a slope steeper than 1 in 21.

2.4103. Permissible Deviations from Slope of Grain Requirements. In the interest of conserving material, the aircraft manufacturer may desire to relax the requirement on slope of grain for those portions of members where stresses are low. Requests for such deviations should be submitted to the procuring or certificating agency for approval. Consideration of such requests by the appropriate agency will be based on revised margins of safety prepared by the aircraft manufacturer in accordance with the appropriate correction factors contained in table 2-1 of ANC-Bulletin 18.

2.411. Scarf Joints.

2.4110. Requirements. The following requirements apply to all scarf joints in solid or laminated aircraft parts:

(1) The slope of scarf should be not steeper than 1 in 15 unless the aircraft manufacturer obtains specific deviations from the procuring or certificating agency on the basis of adequate margins of safety.

(2) The direction of scarf should be related to the direction of grain slope as specified in section 2.4111.

(3) In laminated members the longitudinal distance between the nearest tips of scarfs in adjacent laminations should be not less than 10 times the thickness of the thicker lamination (fig. 2–100).

2.4111. Effect of Sloping Grain on Scarf Joints. The proportion of end grain appearing on a scarfed surface may be greatly increased if the material to be spliced is somewhat cross-grained, and the scarf is made "across" rather than in the general direction of the grain. Since end-grain gluing is more difficult (and results in weaker joints) than side-grain gluing, it follows that where cross grain within the specified acceptable limits is present, all scarf cuts must be made in the general direction of the grain slope (fig. 5–66).

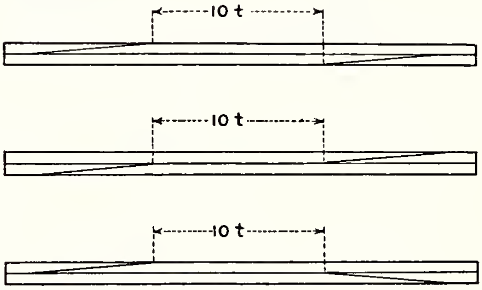

Figure 2–100.—Minimum permissible longitudinal separation of scarf joints in adjacent laminations.

2.4112. Recommendations in Addition to Requirements. It is recommended that, in addition to the specific requirements of the succeeding sections, (1) the number of scarf joints be limited as much as possible, (2) the location be limited to the particular portions of a member where margins of safety are most adequate and stress concentrations are not serious, and (3) special care be exercised to employ good technique in all phases of the preparation, gluing, and pressing operations. It is particularly important that these recommendations be followed in the case of solid spars and flanges and those having few laminations.

2.412. Moisture Content. Each piece of lumber at the time of fabrication shall have been dried to an average moisture content not less than 8 percent and not greater than 12 percent by careful air drying, by kiln drying in accordance with the latest issue of Specification AN–W–2, "Wood; Method for Kiln Drying," or by a combination of air-drying and kiln-drying processes. The spread in moisture content among laminations in the same assembly should not exceed 2 percent at the time of assembly. Also, laminations should be dried to such a moisture content that the water added with the glue will not raise the moisture content above 12 percent (table 5–11).

Regardless of the method of drying, the requirements of paragraph G–3 of AN–W–2 relative to freedom from case-hardening stresses, uniformity of moisture content, etc., should be observed.

2.413. Rings per Inch. The number of annual rings in any 1 inch measured in a radial direction on either end section of a lamination or of a part should not be less than required by the Army-Navy aeronautical specification for the species (table 2-13). If the radial dimension of the piece is less than 1 inch, there should be at least a proportionate number of rings.

TABLE 2-13.—*Limits of specific gravity and rings per inch in current AN specifications.*

Species	AN specification number	Allowable values		
		Specific gravity		Rings per inch
		Minimum	Maximum	Minimum number
Cedar, Port Orford (*Chamaecyparis lawsoniana*).	AN-C-72a	0.40		8
Fir, Douglas (*Pseudotsuga taxifolia*):				
Class N	AN-F-7a	.45		8
Class L	AN-F-7a	.38	.47	6
Fir, noble (*Abies nobilis*)	AN-F-6a	.36		6
Hemlock, western (*Tsuga heterophylla*)	AN-H-4a	.40		6
Pine, eastern white (*Pinus strobus*)	AN-P-16	.34		6
Pine, sugar (*Pinus lambertiana*)	AN-P-19	.34		7
Pine, western white (*Pinus monticola*)	AN-P-18	.38		6
Poplar, yellow (*Liriodendron tulipifera*)	AN-P-17b	.38		6
Spruce, red (*Picea rubra*)	AN-S-6a	.36		6
Spruce, Sitka (*Picea sitchensis*)				
Spruce, white (*Picea canadensis*)				

2.414. Specific Gravity. The specific gravity of any piece or part, based on weight and volume when oven dry, should be within the limits given in the Army-Navy aeronautical specification for the particular species of wood (table 2-13). Methods for determining specific gravity are discussed in section 2.20. Some of the AN specifications list limiting values of weight per cubic foot, and these may be used in lieu of the specified values of specific gravity.

2.415. Sapwood. Bright sapwood should not be considered a defect. Aircraft parts should conform to current AN specifications with respect to the permissibility of sap-stained material.

2.416. Indented Rings. Indented rings or "bear scratches" should not be considered defects.

2.417. Decay and Stain. All parts shall be free from rot, dote, red heart, purple heart,[4] heart stain, or other form of decay. Care should be exercised to avoid mistaking for decay some of the distinctive shades of color that occur in sound material of various species.

2.418. Shakes, Splits, or Compression Failures. All parts should be free from shakes, splits, or compression failures.

2.419. Surfacing of Laminations. Laminations should be smoothly surfaced and free from dirt or grease on the surface to be glued. Those that include scarf or edge joints, or both, should be surfaced subsequent to the formation and gluing of such joints. (See also conditioning of glued stock, sec. 5.28.)

2.4190. Compression Wood. Compression wood of such a character that "cross-breaks" (sec. 2.306) are present should not be permitted in any part.

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[4] A purplish color and other colorations are often natural and inherent in yellowpoplar and if the wood is sound these are acceptable.

2.42. Requirements for Wood Spars and Spar Flanges.

2.420. General. The requirements stated for spar flanges relate specifically to a one-part flange as in a typical box spar with two shear webs. When the flange is divided into two or more parts as in a spar of I–, multiple I–, or multiple box-section the requirements stated apply to each such part.

"Vertical" and "horizontal" as used in expressing the requirements for spars and spar flanges refer respectively to vertical and chordwise directions in a wing spar. "Depth" and "width" likewise refer respectively to the vertical and chordwise dimensions of a wing spar or a flange of a wing spar. These terms are to be appropriately interpreted when considering a spar that is otherwise positioned.

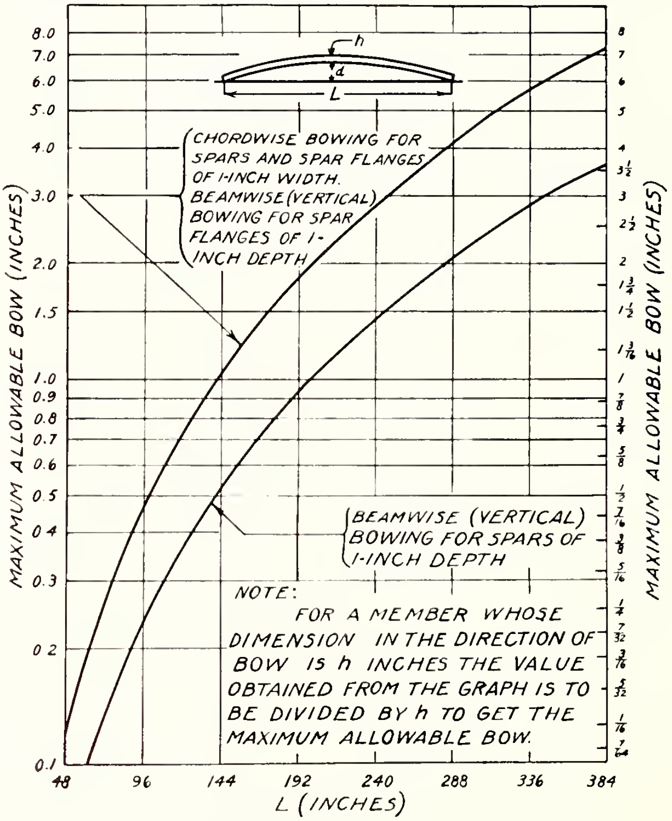

Figure 2–101.—Straightness requirements for spars and spar flanges.

2.4200. Straightness. In measuring the deviation from straightness, a member should be so supported that it is not deflected by its own weight.

2.42000. Spars. The maximum deviation from straightness of a finished spar, prior to its assembly into the structure, should not exceed the following limits:

$$\text{Maximum deviation}=\left(\frac{L}{100}\right)^2/4h \text{ inches in the beamwise (vertical) direction.}$$

$$\text{Maximum deviation}=\left(\frac{L}{100}\right)^2/2h \text{ inches in the chordwise (horizontal) direction}$$

where,

L=length in inches over which the bowing occurs.

h=dimension in inches of the member in the direction of bow.

2.42001. Spar Flanges. The maximum deviation from straightness of a finished solid or laminated spar flange, prior to being glued to the spar webs should not exceed $(L/100)^2/2h$ in either the beamwise or chordwise direction.

2.42002. Graph for Allowable Bowing. The straightness requirements for a spar or spar flange are readily determined from figure 2–101. Example, for a spar length of 16 feet (192 inches), the allowable beamwise bow for a spar 1 inch deep is read from the lower curve as 0.93 inch and if a spar of this length is 5½ inches deep the allowable bow is 0.93÷5½=0.17.

2.4201. Knots. Knots are to be measured on the surfaces on which they appear. In the subsequent detailed limitations of knots in solid spars or spar flanges and in laminations for spars or spar flanges "size" means the distance between lines enclosing the knot and parallel to the edges of the face on which the knot appears and "diameter" is the minimum distance between parallel lines (in any direction) enclosing the knot (fig. 2–102). When the same knot shows on opposite faces of a piece (spar, spar flange, or lamination), the average of the measurements on the two faces should be taken as the size or diameter and this average shall be included but once in the sum of the sizes or diameters within a specified length or area.

In addition to the limitations stated no knot shall exceed ½ inch in size or diameter. Knots less than 1/16 inch in size or diameter should be disregarded in applying limitations of individual knots but should be included in limitations of the sums of sizes or diameters. When two or more knots are close together forming a cluster around which the grain is deflected as a unit, the cluster shall be subject to the same limitations as individual knots.

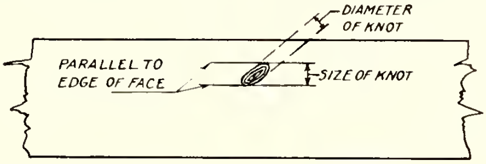

FIGURE 2–102.—"Size" and "diameter" of knot.

2.4202. Compression Wood. On an edge or on an outer quarter of the vertical face of a solid or a horizontally laminated spar or on any surface of a solid spar flange, compression wood should not be permitted in streaks wider than one-fourth inch and the aggregate width of compression wood on any of these surfaces should not exceed one-sixth the thickness of the spar, or one-sixth the depth of the spar flange, whichever is the less.

In vertically laminated spars compression wood should not be permitted in streaks wider than ¼ inch on an outer quarter of the depth of a lamination and the aggregate width of compression wood in such an outer quarter, or on an edge of the spar, should not exceed one-sixth the thickness of the spar.

In the laminations of a spar flange, compression wood should not be permitted in streaks wider than ¼ inch and the aggregate width of compression wood on the face of a lamination, or on any surface of the flange, should not exceed one-sixth the least dimension of the flange.

Within the middle half of the depth of a solid spar or of a lamination in a vertically laminated spar compression wood should not be permitted in streaks wider than ½ inch and the aggregate width of compression wood should not exceed one-tenth the depth of the spar or lamination.

2.4203. Dihedral. Dihedral in horizontally laminated spars or spar flanges may be produced by bending the assembly immediately after the glue is spread. The minimum radius of curvature to which any lamination is bent should be not less than 500 times the thickness of that lamination.

2.421. Requirements for Solid Spars.

2.4210. Definition. A solid spar is a spar whose cross section is composed of a single piece of wood.

2.4211. Annual Ring Direction (fig. 2–103). The spar should be edge-grained over not less than two-thirds the depth of both vertical faces.

2.4212. Knots (see also sec. 2.4201). Within either outer quarter of the spar depth, the size of a knot (on the edge or on either vertical face) should not exceed $\frac{1}{16}$ W (W = the width of the spar); the sum of the sizes of all knots (on the edge and in the adjacent quarters of the vertical faces) within any length equal to 5 W should not exceed $\frac{1}{8}$ W and the sum within any length equal to W should not exceed $\frac{1}{16}$ W.

Within the middle half of the spar depth the diameter of a knot should not exceed $\frac{1}{2}$ W and the sum of the diameters of all knots on one face within a length equal to 5W should not exceed $\frac{1}{2}$ W.

2.4213. Pitch or Bark Pockets. A pitch or bark pocket should be not deeper than $\frac{1}{8}$ W; not wider than $\frac{1}{4}$ inch or $\frac{1}{8}$ W, whichever is the less; and not longer than 2 inches or four times its distance from a corner of the spar, whichever is the less.

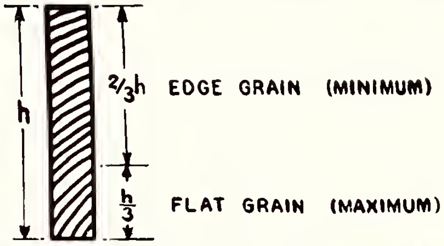

FIGURE 2–103.—Annual ring direction requirements for solid spars.

The distance, measured in any direction, between two pockets on the same face of the spar should be not less than six times the length of the shorter pocket and for pockets in the same growth layer this distance should be not less than six times the length of the longer pocket.

2.422. Requirements for Horizontally Laminated Spars.

2.4220. Definition. A horizontally laminated spar is a spar in which the cross section is made up of two or more laminations glued together and in which the principal glue planes are horizontal. In spars that taper in depth, laminations should be parallel to the edge at which the tensile stress is greatest.

Because of difficulties, waste, and duplication involved in the gluing, pressing, and finishing of an assembly whose depth in the direction of the gluing pressure is several times as great as its thickness (as, for example, in a spar 5 inches deep by 1 inch thick), horizontally laminated spars should preferably be made up in multiple thickness for subequent resawing and finishing, rather than singly.

2.4221. Annual Ring Direction (fig. 2–104). Laminations should be edge-grained on those faces which will be vertical in the finished spar.

2.4222. Knots (see also sec. 2.4201). Within either outer quarter of the spar depth, the size of a knot in a lamination whose vertical dimension is greater than one-eighth the spar depth should not exceed $\frac{1}{16}$ W, the sum of the sizes within a length of the lamination equal to 5 W should not exceed $\frac{1}{8}$ W, and the sum within a length equal to W should not exceed $\frac{1}{16}$ W.

Within either outer quarter of the spar depth the size of a knot in a lamination whose vertical dimension is one-eighth the spar depth or less should not exceed ⅒ W, the sum of the sizes of all knots within a length of the lamination equal to 5 W should not exceed ⅕ W, and the sum in a length equal to W should not exceed ⅒ W.

Within the middle half of the spar depth, the diameter of a knot in any lamination should not exceed ½ W and the sum of the diameters of all knots in a length of the lamination equal to W should not exceed ½ W.

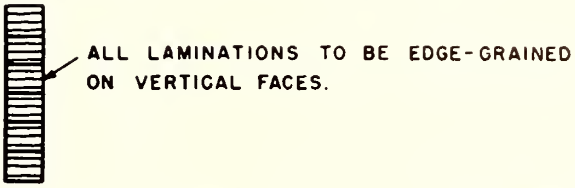

FIGURE 2-104.—Annual ring direction requirements for horizontally laminated spars.

2.4223. Pitch or Bark Pockets. A pitch or bark pocket in any lamination should be not deeper than ⅛ W or one-half the vertical dimension of the lamination, whichever is the lesser; not wider than ¼ inch or ⅛ W, whichever is the lesser; and not longer than 2 inches with the further requirement that a pocket on a face of the spar should be not longer than four times its distance from a corner of the spar. The distance, measured in any direction, between two pockets on the same face of the spar should be not less than six times the length of the shorter pocket and for pockets in the same growth layer, this distance should be not less than six times the length of the longer pocket.

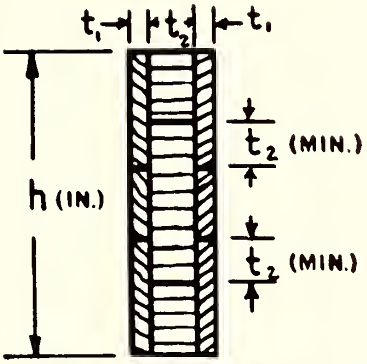

FIGURE 2-105.—Acceptable practice for building up vertical laminations.

2.423. Requirements for Vertically Laminated Spars.

2.4230. Definitions (fig. 2-105). A vertically laminated spar is a spar whose cross section is made up of two or more laminations and in which the principal glue lines are vertical.

2.4231. Annual Ring Direction (fig. 2-106). Face laminations should be edge-grained on their vertical faces. In spars consisting of four or more laminations, flat-grained laminations may be used in pairs provided the individuals of each pair are located and oriented symmetrically with respect to the vertical central plane of the spar and provided the total thickness of flat-grained laminations does not exceed 50 percent of the spar thickness. Single piece laminations (namely, laminations without edge joints) that are flat-grained in one-third or less of their width may be used as edge-grained laminations provided they are symmetrically located and oriented in pairs.

Laminations that are equidistant from the vertical central plane of the spar should be of the same thickness as well as of the same character with respect to being edge-grained or flat-grained. For the required symmetry all pieces edge or scraf jointed together to form a flat-grained lamination must be oriented with the annual rings facing the same way (fig. 2–107).

2.4232. Knots (see also sec. 2.4201). Within either outer quarter of the spar depth the size of a knot (on the edge or on either vertical face) in a lamination should not exceed $\frac{1}{16}$ W with the further limitation that the size of a knot on the narrow face of a lamination should not exceed $\frac{1}{4}$ the width of that face. The sum of the sizes of all knots in a lamination within a length equal to 5 W should not exceed $\frac{1}{8}$ W and within any length equal to W the sum should not exceed $\frac{1}{16}$ W.

Within the middle half of the spar depth, the diameter of a knot in a lamination should not exceed $\frac{1}{2}$ W and the sum of the diameters of all knots in a lamination within a length equal to 5 W should not exceed W.

2.4233. Pitch or Bark Pockets. A pitch or bark pocket in any lamination should be not deeper than $\frac{1}{8}$ W or one-half the thickness of the lamination, whichever is the lesser; not wider than $\frac{1}{4}$ inch or $\frac{1}{8}$ W, whichever is the lesser, and not longer than 2 inches with the further requirement that a pocket on a face of the spar should be not longer than four times its distance from a corner of the spar.

The distance, measured in any direction, between two pockets on the same face of the spar should be not less than six times the length of the shorter pocket and for pockets in the same growth layer this distance should be not less than six times the length of the longer pocket.

2.424. Requirements for Solid Spar Flanges.

2.4240. Definition. A solid spar flange is a spar flange whose cross section consists of a single piece of wood.

2.4241. Annual Ring Direction. Solid spar flanges may be either edge-grained or flat-grained on their horizontal faces (sec. 2.401).

2.4242. Knots (see also sec. 2.4021). On any face of a solid spar flange, the size of a knot should not exceed $\frac{1}{16}$ W (W=the width of the face on which the knot appears); the sum of the sizes of all knots within any length equal to 5 W should not exceed $\frac{1}{8}$ W; and the sum in a length equal to W should not exceed $\frac{1}{16}$ W.

2.4243. Pitch or Bark Pockets. A pitch or bark pocket should be not deeper than one-eighth the dimension of the flange in the direction of the depth of the pocket; not wider than $\frac{1}{4}$ inch or one-eighth the dimension of the flange in the direction of the width of the pocket, whichever is the lesser; and not longer than four times its distance from a corner of the flange. The distance, measured in any direction, between two pockets on the same face of the flange should be not less than six times the length of the shorter pocket and for pockets in the same growth layer this distance should be not less than six times the length of the longer pocket.

2.425. Requirements for Laminated Spar Flanges.

2.4250. Definition. A laminated spar flange is a flange whose cross section is made up of two or more laminations glued together.

Flanges may be either horizontally or vertically laminated. In horizontally laminated flanges that taper in depth, laminations should be parallel to the face at which the tensile stress is greatest.

2.4251. Annual Ring Direction. Laminated spar flanges may be either edge-grained or flat-grained on their horizontal faces (sec. 2.401).

2.4252. Knots (see also sec. 2.4201). On any face of a lamination whose cross section exceeds one-third the cross section of the flange, the size of a knot should not exceed $\frac{1}{16}$ W (W=the width of the corresponding face of the flange).

On any face of a lamination whose cross section does not exceed one-third the cross section of the flange, the size of a knot shall not exceed $\frac{1}{10}$ W except that the size of a knot on the narrow face of a lamination should not exceed one-fourth the

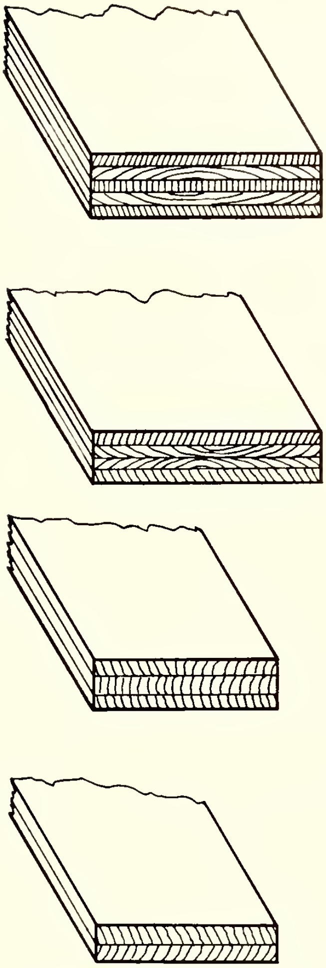

FIGURE 2-106.—Lamination arrangement and permissible combinations of edge-grained and flat-grained laminations in vertically laminated spars. Spars to be symmetrical about vertical central plane.

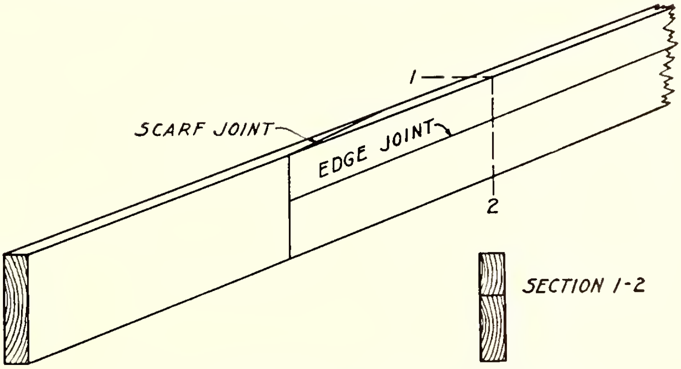

FIGURE 2-107.—Orientation of growth layers in built-up lamination.

width of that face. (Knots less than 1/16 inch in size are to be disregarded in accordance with sec. 2.4201.)

The sum of the sizes of all knots on any face of a lamination in a length equal to the width of that face should not exceed the size of the largest knot permitted on that face, and the sum of the sizes in a length equal to five times the width of the face should not exceed twice the size of the largest single knot permitted.

2.4253. Pitch or Bark Pockets. A pitch or bark pocket in any lamination should be not deeper than one-eighth the dimension of the flange in the direction of the depth of the pocket or one-half the thickness of the lamination, whichever is the lesser; not wider than ¼ inch or one-eighth the dimension of the flange in the direction of the width of the pocket, whichever is the lesser; and not longer than four times its distance from a corner of the flange. On any face of the flange, the distance, measured in any direction, between two pockets should be not less than six times the length of the shorter pocket, and for pockets in the same growth layer this distance should be not less than six times the length of the longer pocket.

2.426. Requirements for Stressed Parts of Small Cross Section as Compared to Their Length, Such as Cap Strips, Verticals, and Diagonals of Ribs; Skin-stiffeners; Longerons; Etc.

2.4260. General. All such parts into which nails are to be driven should be free of knots or other defects which interfere with nailing or are likely to cause splitting in nailing.

2.4261. Annual Ring Direction. Those faces of cap strips, verticals, and diagonals of trussed ribs that are parallel to the plane of the rib should preferably be edge-grained.

2.4262. Knots. Knots may be permitted in the middle half of the width of a flat-sawed face, provided the diameter of any one knot does not exceed one-eighth the width of the face, and provided such knots do not cause deviations of grain in the outer quarters steeper than the allowable value.

2.4263. Pitch or Bark Pockets. No pitch or bark pockets should be permitted in members that are less than 1 inch in either cross-sectional dimension. Pitch or bark pockets may be permitted in an edge-grained face (if it is wider than 1 inch), provided their dimensions do not exceed a depth of one-eighth the dimension of the piece parallel to the depth of the pocket; a width of one-eighth the width of the face on which they appear; and a length not greater than 2 inches, or four times the distance of the pocket from the edge of the piece, whichever is the less.

The distance, measured in any direction, between two pockets should be not less than six times the length of the shorter pocket, except that where they are in the same line, the distance between pockets should be not less than six times the length of the longer pocket.

2.4264. Compression Wood. No compression wood should be permitted in parts which are less than 1 inch in either cross-sectional dimension. In larger parts, compression wood may be permitted in streaks not wider than one-twentieth the width of the face and aggregating not more than one-tenth the width of the face on which they appear.

2.427. Requirements for Curved Laminated Members, Such as Fuselage Rings, Door Frames, and Wing-Tip Bows.

2.4270. Annual Ring Direction. Material for curved parts should preferably be flat-grained on the faces, which will be curved after gluing in order to minimize changes in curvature with moisture-content changes.

2.4271. Knots. Material for this use shall be free of knots of such size as would interfere with bending to the required curvature or with good contact between laminations.

2.4272. Compression Wood. Material for such use should be free from compression wood.

CHAPTER 3. MODIFIED WOOD

3.0. PLYWOOD, LAMINATED WOOD, COMPREG, IMPREG, HEAT-STABILIZED WOOD, AND PAPREG.

3.00. General. Useful as wood is in the form in which nature provides it, science has shown the way to transformations that add greatly to its utility. Among the modified wood products of present and potential use in aircraft are plywood, laminated and curved members, resin-impregnated and compressed wood, heat-stabilized wood, and high-strength, resin-treated paper.

3.1. PLYWOOD.

3.10. General. Plywood is an assembled product of wood and glue that is usually made of an odd number of thin plies (veneers), with the grain of each layer at an angle of 90° with the adjacent ply or plies. The outside plies are termed "faces," or "face and back," and the inner plies are termed "core and cross bands." In three-ply plywood the center ply is the core, and its grain is at an angle to the face plies. In panels with five or more plies, the center ply is the core, and the inner plies whose grain is at an angle to the faces and core are called cross bands.

The chief advantages of plywood as compared with solid wood are its more nearly equal strength properties along the length and width of the panel, greater resistance to checking and splitting, and almost negligible change in width and length with changes in moisture content (sec. 3.11).

These advantages are obtained by alternating the direction of grain in the successive plies. Since the strength of wood across the grain is much lower than along the grain, equalization of strength properties in a plywood panel is approached through an increase in strength in one direction accompanied by a decrease in strength in the other direction.

The tendency of cross-banded products to warp as the result of stresses set up from shrinking and swelling with moisture-content changes is largely eliminated by balanced construction. This construction consists of arranging the plies in pairs about the core or central ply so that for each ply there is an opposite, similar, and parallel ply. Matching the plies involves a consideration of (1) thickness, (2) kind of wood with particular reference to shrinkage and density, (3) moisture content at the time of gluing, and (4) angle or relative direction of the grain.

Plywood for aircraft is sometimes made with an even number of plies or with the grain of adjacent plies at angles other than 90°. Plywood panels are also made with the grain of alternate plies at 90° but with the grain of the faces at other than 0° or 90° with the edges of the panel. Nonsymmetrical plywood is not standard and should be used with caution, because its unbalanced construction is likely to cause warping of the panels.

Plywood for aircraft is produced in flat, curved, or molded form, using glues of the thermosetting, synthetic-resin type. Aircraft flat plywood is produced between the heated platens of a hydraulic press and is commonly referred to as hot-press plywood, whereas molded plywood is usually produced by means of fluid pressure applied through an impermeable bag or blanket in an autoclave and is referred to as bag-molded or fluid-pressure-molded plywood. Curved plywood may be produced by gluing veneer over curved forms in a press, by bending flat plywood over a form, or by bag molding.

The quality requirements for plywood to be used in aircraft are much more exacting than for industrial plywood in general. Current requirements are published in Army-Navy Aeronautical Specification (AN–NN–P–511b) Plywood and Veneer; Aircraft Flat Panel, and Army-Navy Aeronautical Specification (AN–P–43) Plywood; Aircraft, Molded (fluid pressure).

The quality of plywood is contingent upon (*a*) the kind and quality of veneer used (sec. 2.320), (*b*) the adhesive used (sec. 4.0), and (*c*) the technique employed in combining the veneer and adhesive to produce the finished panel.

3.11. Shrinkage of Plywood. Shrinkage in thickness of the plies is unopposed, hence a plywood panel for all practical purposes will shrink in thickness like normal wood. Since the longitudinal shrinkage of a ply is negligible, the lateral shrinkage of adjacent plies (whose grain is at right angles) will be restrained. The shrinkage of a plywood panel, then, in the two lateral directions, will be relatively small. This shrinkage will vary with the species, the ratio of ply thicknesses, the number of plies, the character of the grain, and the combination of species. The average shrinkage obtained from several hundred tests on a variety of combinations of species and thicknesses in bringing three-ply wood from the soaked to the oven-dry condition was about 0.45 percent parallel to the face grain and 0.67 percent perpendicular to the face grain, with ranges of from 0.2 to 1 percent and 0.3 to 1.2 percent, respectively. Individual cases of some species may give wider ranges than these. The species included in the tests were basswood, birch, black walnut, chestnut, elm, mahogany, Spanish cedar, spruce, sugar maple, sweetgum, tupelo, and yellowpoplar. From this it is seen that the lateral shrinkage of plywood is only about one-tenth as great as that across the grain of an ordinary board. The total lateral shrinkage of a 1⅞-inch southern yellow pine board with two 1/12-inch sweetgum veneers glued to the faces was only 1 percent, or about one-seventh of the normal shrinkage. The values given for shrinkage are based on a moisture content change ranging from a green or soaked condition to an oven-dry condition. In service, the change in moisture content will be much less, generally not more than enough to cause a dimensional change of one-fourth, though it might at times reach one-half of that represented in the tests.

3.12. Manufacturing Defects. The effects of variations in technique are sometimes apparent from visual inspection but are often manifest as inferior glue lines which can only be detected by testing a panel or portions of it to destruction. It is therefore important that careful supervision be maintained over the production of aircraft plywood.

Examples of manufacturing defects that can be visually detected include blisters, core laps or core voids, and sometimes excessively glazed surfaces and "bleed through" (sec. 5.212).

Blisters usually develop from an accumulation of steam within a panel in local areas of excess moisture during the pressing operation. They can usually be detected quickly by an inspector who is looking between the platens of the press just as they open. After the panels have cooled, a blister can often be detected by tapping the surface of the panel with the knuckles or a pencil and listening for the change in sound as tapping proceeds from solid to blistered areas.

Core laps and core gaps are obvious. On the other hand, panels can have glue bonds which are below acceptable standards even though good veneer and adhesives are used. This fact can escape detection under visual examination only.

Unsatisfactory glue bonds can result from (*a*) improper moisture content of veneer, (*b*) improper amount of glue spread (sec. 5.23), (*c*) too long assembly time (sec. 5.24), (*d*) excessive time in loading and closing press (when panels lie on the hot plates before pressure is applied the glues tend to precure), (*e*) improper temperature and pressure (secs. 5.25 and 5.26), or (*f*) insufficient curing time (sec. 5.263). While small variations from accepted practice in any one of these conditions would be unlikely to lower glue bond quality dangerously, a combination of small variations of several conditions may result in below-standard plywood.

3.13. Weights of Veneer and Plywood. Table 3–1 gives the weight per square foot of veneers of various thicknesses and corresponding pounds per cubic foot and specific gravity based on weight and volume when oven dry. The table also gives the weight per square foot of veneer at 10-percent moisture content. At the bottom of table 3–1 approximate values for weight per square foot of glue line are given for film glue, cold-setting resin glue, hot-setting resin glue, and casein glue, which should be taken into consideration when the table is used for estimating the weight of plywood. Table 2–4 lists the average specific gravity and pounds per cubic foot of a number of species commonly used in aircraft.

3.2. GLUED LAMINATED MEMBERS.

3.20. General. Glued laminated construction is an assembly of two or more layers of wood which have been glued together with the grain of all layers or laminations approximately parallel. In aircraft, laminated construction is used for such parts as propellers, spar flanges, bulkhead rings, filler blocks, bearing blocks, rib members, and wingtip bows.

The laminations may be produced from either lumber or veneer. As used for making aircraft parts, laminations are usually prepared from dry lumber of less than 1 inch thick and from veneer of one-sixteenth to one-eighth inch in thickness. The laminations may be of one or more pieces, edge glued to provide width and end scarfed to provide length, where necessary. Two or more full-sized laminations are then glued together to produce the thickness of member required.

TABLE 3-1.—*Weight* [1] *in pounds per square foot of oven-dry veneer and of veneer at 10 percent moisture content*

Weight per cubic foot, based on oven-dry weight and oven-dry volume.	Specific gravity based on oven-dry weight and oven-dry volume	Thickness of veneer in inches																							
		0.001		0.011		0.016		0.020		0.030		0.034		0.040		0.047		0.060		0.068		0.080		0.095	
		Oven dry	10-percent moisture content	Oven dry	10-percent moisture content	Oven dry	10-percent moisture content	Oven dry	10-percent moisture content	Oven dry	10-percent moisture content	Oven dry	10-percent moisture content	Oven dry	10-percent moisture content	Oven dry	10-percent moisture content	Oven dry	10-percent moisture content	Oven dry	10-percent moisture content	Oven dry	10-percent moisture content	Oven dry	10-percent moisture content
Pounds		*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*
18	0.288	0.0015	0.0016	0.016	0.018	0.024	0.026	0.030	0.032	0.045	0.048	0.051	0.054	0.060	0.064	0.070	0.075	0.090	0.096	0.102	0.108	0.120	0.128	0.142	0.152
19	.304	.0016	.0017	.017	.018	.025	.027	.032	.034	.048	.050	.054	.057	.063	.067	.074	.079	.095	.101	.108	.114	.127	.134	.150	.159
20	.321	.0017	.0018	.018	.019	.027	.028	.033	.035	.050	.053	.057	.060	.067	.070	.078	.083	.100	.106	.113	.120	.133	.141	.158	.167
21	.337	.0018	.0018	.019	.020	.028	.030	.035	.037	.052	.055	.060	.063	.070	.074	.082	.087	.105	.111	.119	.125	.140	.148	.166	.175
22	.353	.0018	.0019	.020	.021	.029	.031	.037	.039	.055	.058	.062	.066	.073	.077	.086	.091	.110	.116	.125	.131	.147	.154	.174	.183
23	.369	.0019	.0020	.021	.022	.031	.032	.038	.040	.058	.060	.065	.068	.077	.080	.090	.095	.115	.121	.130	.137	.153	.161	.182	.191
24	.385	.0020	.0021	.022	.023	.032	.034	.040	.042	.060	.063	.068	.071	.080	.084	.094	.098	.120	.126	.136	.142	.160	.168	.190	.199
25	.401	.0021	.0022	.023	.024	.033	.035	.042	.044	.062	.065	.071	.074	.083	.087	.098	.102	.125	.131	.142	.148	.167	.174	.198	.207
26	.417	.0022	.0023	.024	.025	.035	.036	.043	.045	.065	.068	.074	.077	.087	.090	.102	.106	.130	.136	.147	.154	.173	.181	.206	.215
27	.433	.0022	.0023	.025	.026	.036	.038	.045	.047	.068	.070	.076	.080	.090	.094	.106	.110	.135	.141	.153	.159	.180	.188	.214	223
28	.449	.0023	.0024	.026	.027	.037	.039	.047	.049	.070	.073	.079	.083	.093	.097	.110	.114	.140	.146	.159	.165	.187	.194	.222	.231
29	.465	.0024	.0025	.027	.028	.039	.040	.048	.050	.072	.075	.082	.085	.097	.100	.114	.118	.145	.151	.164	.171	.193	.201	.230	.239
30	.481	.0025	.0026	.028	.029	.040	.042	.050	.052	.075	.078	.085	.088	.100	.104	.118	.122	.150	.156	.170	.176	.200	.208	.238	.247
31	.497	.0026	.0027	.028	.029	.041	.043	.052	.054	.078	.080	.088	.091	.103	.107	.121	.126	.155	.161	.176	.182	.207	.214	.245	.254
32	.513	.0027	.0028	.029	.030	.043	.044	.053	.055	.080	.083	.091	.094	.107	.110	.125	.130	.160	.166	.181	.188	.213	.221	.253	.262
33	.529	.0028	.0028	.030	.031	.044	.046	.055	.057	.082	.085	.094	.097	.110	.114	.129	.134	.165	.171	.187	.193	.220	.228	.261	.270
34	.545	.0028	.0029	.031	.032	.045	.047	.057	.059	.085	.088	.096	.100	.113	.117	.133	.138	.170	.176	.193	.199	.227	.234	.269	.278
35	.561	.0029	.0030	.032	.033	.047	.048	.058	.060	.088	.090	.099	.102	.117	.120	.137	.142	.175	.181	.198	.205	.233	.241	.277	.286
36	.577	.0030	.0031	.033	.034	.048	.050	.060	.062	.090	.093	.102	.105	.120	.124	.141	.145	.180	.186	.204	.210	.240	.248	.285	.294
37	.593	.0031	.0032	.034	.035	.049	.051	.062	.064	.092	.095	.105	.108	.123	.127	.145	.149	.185	.191	.210	.216	.247	.254	.293	.302
38	.609	.0032	.0033	.035	.036	.051	.052	.063	.065	.095	.098	.108	.111	.127	.130	.149	.153	.190	.196	.215	.222	.253	.261	.301	.310
39	.625	.0032	.0033	.036	.037	.052	.054	.065	.067	.098	.100	.110	.114	.130	.134	.153	.157	.195	.201	.221	.227	.260	.268	.309	.318
40	.641	.0033	.0034	.037	.038	.053	.055	.067	.069	.100	.103	.113	.117	.133	.137	.157	.161	.200	.206	.227	.233	.267	.274	.317	.326
41	.657	.0034	.0035	.038	.039	.055	.056	.068	.070	.102	.105	.116	.119	.137	.140	.161	.165	.205	.211	.232	.239	.273	.281	.325	.334
42	.673	.0035	.0036	.038	.040	.056	.058	.070	.072	.105	.108	.119	.122	.140	.144	.164	.169	.210	.216	.238	.244	.280	.288	.332	.342
43	.689	.0036	.0037	.039	.040	.057	.059	.072	.074	.108	.110	.122	.125	.143	.147	.168	.173	.215	.221	.244	.250	.287	.294	.340	.349
44	.705	.0037	.0038	.040	.041	.059	.060	.073	.075	.110	.113	.125	.128	.147	.150	.172	.177	.220	.226	.249	.256	.293	.301	.348	.357
45	.721	.0038	.0038	.041	.042	.060	.062	.075	.077	.112	.115	.128	.131	.150	.154	.176	.181	.225	.231	.255	.261	.300	.308	.356	.365
46	.737	.0038	.0039	.042	.043	.061	.063	.077	.079	.115	.118	.130	.134	.153	.157	.180	.185	.230	.236	.261	.267	.307	.314	.364	.373
47	.753	.0039	.0040	.043	.044	.063	.064	.078	.080	.118	.120	.133	.136	.157	.160	.184	.189	.235	.241	.266	.273	.313	.321	.372	.381
48	.769	.0040	.0041	.044	.045	.064	.066	.080	.082	.120	.123	.136	.139	.160	.164	.188	.192	.240	.246	.272	.278	.320	.328	.380	.389
49	.785	.0041	.0042	.045	.046	.065	.067	.082	.084	.122	.125	.139	.142	.163	.167	.192	.196	.245	.251	.278	.284	.327	.334	.388	.397
50	.801	.0042	.0043	.046	.047	.067	.068	.083	.085	.125	.128	.142	.145	.167	.170	.196	.200	.250	.256	.283	.290	.333	.341	.396	.405

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[1] For estimating weights of plywood the following values per square foot of glue line may be useful: Film glue, about 0.012 pound; cold-setting resins, about 0.028 pound; hot-setting resins, about 0.025 pound; casein glue, about 0.025 pound. These figures are approximate values only, and in all cases where possible, the weight of dry glue should be calculated from the concentrations and spreads actually used.

A well-laminated wood member is as strong as a solid member of the same wood in the same size. Wood properties, such as slope of grain, density, occurence of wood defects, and the like, affect the strength of the laminated member in the same way that they do a solid wood member. The process of laminating, however, permits the use of small, clear cuttings which can be glued into a member entirely free of such defects, and as a result the laminated member may possess more strength than the similar solid member, especially in the larger sizes. In addition, the process of laminating permits the production of members in sizes that could not readily be supplied in equal quality in solid wood.

Laminated members are made both straight and curved. The laminating of straight members is the simpler operation, usually requiring only conventional equipment but sometimes complicated by the large size of piece produced. In making curved members, forms or jigs must be prepared to the shape of member desired. The laminations are drawn against these forms and are glued together in the curved shape, being held under pressure until the glue has set. Upon removal from the forms, the laminated member retains the approximate curve at which it was glued. In making curved members, the relatively thin individual laminations can be bent into position before gluing with much less stress than is developed in steaming and bending the larger solid member, with the result that the laminated member furnishes a greater strength and stiffness.

The drying of wood in thick sizes is relatively slow, expensive, and often accompanied by drying stresses. The thinner lumber and veneer can be dried much more rapidly and satisfactorily, and the laminating of such lumber or veneer enables the production of heavier members which are uniformly dry and relatively free of drying defects and stresses.

The laminated member is subject to changes in moisture content with variations in atmospheric humidity and to changes in dimension due to shrinking and swelling much the same as similar solid members. Minimizing dimensional changes in both is dependent on having the wood at the right moisture content when fabricated and on the use of moisture-resistant coatings.

Successful lamination of wood members requires that the joints be well glued and that the bond shall be durable under all conditions of service. The glue should develop the full strength of the wood and should further maintain that strength under service conditions. Otherwise delamination of the glue line joint is liable to develop and the strength of the member be seriously reduced. Many glues can be successfully used in producing laminated members.

The use of heat to hasten the setting of the glue is practical with cold-setting glue and may be accomplished by placing the glued assembly in a heated room or kiln. Under heat curing, the wood in the assembly tends to dry out, the surface of the wood shrinks, and the glue joints open before the glue is set, unless the atmosphere surrounding the assembly is humidified so as to maintain a constant moisture content in the assembly. The use of heated kilns also permits the laminating of members with the low-temperature, phenolic-type glues but laminated members of substantial size are usually glued with cold-setting glues to avoid the inconvenience of heating the mass of wood.

Electrical, high frequency heating and bag-molding with steam or steam-air combination are employed for the heating and curing of special laminated aircraft members, but the use of steam-heated hydraulic hot presses is not very practical for laminating heavy wood members.

3.3. RESIN-TREATED PLYWOOD AND LAMINATED WOOD (IMPREG AND COMPREG).

3.30. General. The properties of wood can be modified by resin treatments, and a combination of a resin treatment and compression. Two such woods, "impreg" (resin-impregnated wood) and a dimensionally stable form of "compreg" (resin-impregnated, compressed wood) have been developed at the Forest Products Laboratory.

The proper treatment of wood with suitable resins will greatly reduce the swelling and shrinking of wood and the resultant warping and checking. It will greatly improve the resistance of the wood to moisture transfusion and to decay, and appreciably increase its compressive strength properties. In addition to such improved stability, resin-treated wood when compressed will exhibit an increase in strength properties, other than the compressive properties, about in proportion to the specific gravity to which the wood is compressed.

Because of the difficulty of adequately treating massive pieces of wood, and the further fact that an outer zone treatment with stabilizing resins causes stresses to be set up between the treated and untreated parts of the wood, it seems advisable that, for the present, all impreg and compreg be made from sheets of veneer one-eighth inch thick or thinner. Both materials can be made up in either plywood or parallel-laminated form, depending on the directional distribution of strength properties desired.

3.31. Impreg. Great dimensional stability has been effectively accomplished in wood by treating it with resin-forming systems that penetrate the cell-wall structure and become bonded to the active groups of wood which tend to take up water. Water-soluble, phenol-formaldehyde, resin-forming mixes meet these requirements better than any other resins or resin-forming systems thus far tested. The commercial phenol-formaldehyde resin-forming mixes given in table 3–2 are of this kind and, in experiments at the Forest Products Laboratory, have been found similar in stabilizing effectiveness.

Green veneer direct from the log can be treated with these resins by merely immersing the plies in the treating solution, which has been diluted to a solids content of 40 to 50 percent with water, for periods of time ranging from about 1 hour to 1 day, depending on the moisture content, thickness, and species of veneer.

Dry veneer can be treated by the cylinder-treating method by applying air pressures of 20 to 100 pounds per square inch to the veneer immersed in the treating solution. This treatment requires from 15 minutes to 2 hours, depending on the species. The resinoid is carried only into the coarse capillary structure; the veneer should, therefore, be close-piled under nondrying conditions for 1 to 2 days following treatment to insure a uniform diffusion of the resinoid throughout the cell-wall structure. The treated veneer is then dried by stickering in a kiln or passing through a continuous drier at a temperature of about 160° F.

TABLE 3–2.—*Seven commercial phenol-formaldehyde resin-forming mixes*

Manufacturer	Resinoid	Resin-forming solid content [1]
Bakelite Corporation	BR5995	61
Bakelite Corporation	BR15100	71
Casein Co. of America	Compregnite	59
Central Process Corporation	1650	54
Durez Plastics & Chemical Corporation	6686	43
Monsanto Chemical Co	461	72
Resinous Products & Chemical Co	PR50	55

[1] As determined at the Forest Products Laboratory by polymerization in a pressure bomb.

When thoroughly dry, the treated veneer is heated to about 200° F. for 20 hours, or 300° F. for one-half hour, to set the resin in the structure. These treated and cured plies can be assembled with practically any kind of glue—animal, vegetable (starch), soybean, casein, or both hot- and cold-press, synthetic-resin glues of both the phenol-formaldehyde and urea-formaldehyde types (sec. 5.2720) but only the synthetic-resin glues are acceptable for aeronautical use. On the basis of tests at the Forest Products Laboratory, however, only the synthetic-resin glues are recommended for assembly of resin-treated and cured plies that are for aeronautical use. Glues containing considerable solvent should be allowed to dry, after application to the treated veneer surfaces, to a greater extent before assembly than is necessary in gluing ordinary wood. In gluing experiments, open assembly times of 15 minutes produced joints that failed 100 percent in the wood when tested.

Further details regarding the treating, drying, and assembly of resin-treated wood are given in Forest Products Laboratory Restricted Mimeograph No. 1380 (*3–4*).

Impreg can be made from a number of different species. As most of its properties other than strength are largely independent of species, the chief basis for selection of a particular species should be the desirability of its mechanical properties and ease of treatment. Practically all softwoods, except the resinous pines, may be treated readily, as may the softer hardwoods, such as cottonwood, basswood, poplar, and the gums. Birch and the sapwood of maple take the treatment best of the harder hardwoods.

An increase of 30 percent in the weight of the wood was accompanied by a volume increase of about 10 percent. Impreg of different species will hence have a specific gravity about 18 percent greater than that of untreated wood.

A comparison of various properties with those of normal wood is given in table 3–3.

3.32. Compreg. The chief object of making compreg is to combine the improved mechanical properties that result from compression with the degree of stability needed for specific uses. Compreg can be made in variations ranging from material that has been superficially treated with a nonstabilizing resin to that which has been thoroughly treated throughout the cell-wall structure with a stabilizing resin prior to compression. The least stable form—which, strictly speaking, should be called densified wood rather than compreg—is made from thin plies of veneer (about one-fortieth of an inch thick or less) which are reported to be treated with bonding resin under high compressing pressures. Actually, only the open-pore structure at the surface can be penetrated in this way. Another method is to coat the plies several times with an alcoholic solution of a phenolic resin, allowing the solution to be taken up by capillarity and diffusion within the structure between successive spreads. This method gave considerably more penetration than the aforementioned procedure, but the distribution of resin was still far from uniform even in the microscopically visible structure. Prolonged soaking of the veneer in the alcoholic resin solution or treating under vacuum or pressure in a treating cylinder further improved the distribution of resin in the coarse capillary structure and gave a limited penetration of the cell walls. When the water-soluble stabilizing resins were used under the conditions given for making impreg, the entire capillary structure, including that within the cell-wall structure, was penetrated, thus making possible a more stable product.

Table 3–3.—*Properties of Forest Products Laboratory impreg compared with normal wood*

Property	Compared with normal wood
Moisture resistance:	
Rate of moisture absorption, swelling, shrinking.	Much smaller.
Equilibrium adsorption of water vapor	25 to 40 percent as much.
Equilibrium swelling and shrinking	25 to 40 percent as much.
Absorption of water on prolonged immersion	Slightly less.
Moisture tranfusion through wood under relative humidity gradient.	4 to 8 percent as rapid.
Weathering	Vastly improved.
Chemical resistance—	
To acids	High.
To alkalies	Moderate to low.
To organic solvents	High.
Resistance to attack by—	
Wood-destroying fungi	Higher than nondurable woods, on basis of 2-year exposure to conditions under which untreated sapwood controls decayed badly in 6 months.
Termites	High, on same basis as above.
Electrical resistance—	
At 30 percent relative humidity	2 to 10 times. Specific resistance 10^{13} ohms.
At 90 percent relative humidity	1,000 to 10,000 times. Specific resistance 2×10^{10} to 2×10^{11} ohms.
Heat conductivity	Approximately 7 percent higher.
Fire resistance	Inappreciably different. Weight loss only in direct proportion to resin content. (Preliminary tests indicate that ammonium phosphate can be incorporated with resin at time of treatment, fixing the salt in the structure and giving appreciably increased fire resistance.)
Finishing:	
Painting	Few tests made confined to white house paints. After 4 years' exposure, impreg panels with no primer superior to controls with no primer, as good as controls with primer. Showed no loss of paint film. Some alligatoring.
Lacquer finishes	No data.
Strength	Only compressive properties improved.

Compreg is made from dry, resin-treated plies either with or without the use of additional glue. The resin treatments which give the poorest distribution of resin throughout the structure in general give sufficient resin on the surface for bonding. Naturally dense veneer that is thoroughly treated with a stabilizing resin will, under some conditions, require the use of additional glue to obtain optimum shear strength between plies.

The pressure required for compression will vary with the species, the degree of compression desired, and the nature of the treating resin. Stabilizing resinoids, which enter the cell-wall structure, plasticize the wood prior to setting of the resin to an extent sufficient to permit compression under considerably lower pressures than are needed for wood containing appreciably preformed resin. Pressures ranging from about 250 to 3,000 pounds per square inch are used for making a product ranging in specific gravity from 1.0 to 1.4.

Because of the prohibitive time necessary to heat the center of the material properly, compreg can be economically made by the conventional method of pressing between heated hot plates only up to thicknesses of about 2 inches. Compreg up to 6 inches in thickness has been made by the electrostatic heating method, by which heat is generated throughout the specimen. Blocks 6 inches thick have also been made by a preheating process. By this method the separate plies, when ready for assembly, are heated in racks in a kiln, or in a continuous drier, to 230° F. for 10 minutes, then rapidly piled and rushed to the press. Practically no cooling of the center of the pile occurs while this is being done, and the sides can be rapidly reheated. The treated plies are very plastic at this temperature, and uniform compression of all the plies occurs simultaneously. By this method it is only necessary to add sufficient heat to raise the temperature 20° F. when stabilizing resins are used. At 250° F. the exothermic resin-forming reaction becomes sufficiently intense to raise the temperature automatically to the desired temperature of 290° to 300° F.

Thick compreg can also be made up by gluing thinner panels together. Compreg can be glued to itself, to impreg, or to ordinary wood only after the surface glaze is removed by sanding or milling (sec. 5.2721). Satisfactory joints have been obtained with cold-setting phenolic and urea glues and with thermoplastic glues. A means of gluing compreg more readily is given in section 3.33.

Mechanically the dimensionally stable and less stable forms of compreg are practically identical except for notched impact strength. The thorough distribution of resin throughout the structure seems to increase the notch sensitivity of the wood to some extent. Low-resin-content, nonstabilized forms of compreg are also more easily glued than the higher-resin-content forms. For uses where notch sensitivity is more critical than moisture resistance, the less stable forms of compreg may be preferable; but for most uses the stable types are to be preferred.

As the mechanical properties of compreg are less dependent upon the species from which it is made than are those of impreg, a broad range of species can be used. The chief species limitation in making compreg, as with impreg, is the choice of readily treatable woods. Woods with extremely contrasty grain (marked differences in density between springwood and summerwood) should be avoided, as it is difficult to make compressed surfaces that are free from raised grain from such material.

For details of manufacture of the dimensionally stable type of compreg, see Forest Products Laboratory Restricted Mimeograph No. 1381 (*3–5*).

The specific gravity of compreg can vary all the way from that of impreg to about 1.4. In general, the high specific gravity material is referred to when the specific gravity is not given.

Other properties of compreg, both the stabilized Forest Products Laboratory form and an unstabilized form, are given in table 3–4. A comparison of the moisture-absorption and swelling characteristics of Forest Products Laboratory compreg and unstabilized compreg for varying immersion periods is given in table 3–5.

TABLE 3–4.—*Properties of compreg (stabilized and unstabilized forms) compared with normal wood*

Property	Stabilized form [1] compared with normal wood	Unstabilized form compared with normal wood
Moisture:		
Rate of moisture absorption and swelling and shrinking.	Considerably less than for impreg as well as for normal wood. See table 3–5. Laminated spruce specimens, 0.4 x 2.5 x 2.5 inches, immersed in water, absorbed 0.5 percent moisture in 1 day, 1.2 percent in 4 days, 1.8 percent in 7 days.	Considerably less. See table 3–5.
Equilibrium adsorption of water vapor.	25 to 40 percent as much. Actual adsorption 5 to 10 percent.	About the same.
Equilibrium swelling and shrinking.	Same as impreg at right angles to direction of pressing.	Equilibrium swelling (including recovery from

[1] Forest Products Laboratory compreg.

TABLE 3–4.—*Properties of compreg (stabilized and unstabilized forms) compared with normal wood*—Con.

Property	Stabilized form [1] compared with normal wood	Unstabilized form compared with normal wood
Equilibrium swelling and shrinking.	Greater in direction of pressing by the multiple factor (Sp. gr. of compreg divided by that of impreg). Equilibrium swelling in thickness direction: 5 to 10 percent.	compression) in thickness direction. Low resin content: 40 to 60 percent. High resin content: 20 to 25 percent.
Moisture transfusion through wood under relative humidity gradient.	2 to 5 percent as rapid	No data.
Chemical resistance:		
To acids	High	No data.
To alkalies	Moderate to low	No data.
To organic solvents	High	No data.
Decay resistance	At least as good as impreg	No data.
Electrical resistance (D. C.).	Similar to impreg. Approaches equilibrium conditions more slowly.	No data, as electrical conductivity is a function of adsorbed moisture, very little improvement would be expected.
Heat conductivity	Practically the same as for wood of same specific gravity [2] 2.0 B. t. u. per hr. per sq. ft. per inch per °F. (5.8 C. G. S. units) for sp. gr. 1.35.	No data, should be similar to stabilized form.
Fire resistance	About the same as for wood of the same specific gravity.	No data, should be similar to stabilized form.
Finishing	Has naturally hard, smooth, water-resistant faces which cannot be improved by applied clear finishes. Can be sanded and buffed on cut surfaces to give finish similar to that of original faces.	Has naturally hard, smooth faces. Clear finishes improve water resistance.
Lacquers and enamels	Both one sprayed coat of a yellow lacquer and a yellow enamel used by the Army for painting insignia on metal airplanes has stood up well to weather exposure for over 1 year.	No data.
Machining	With suitable tools, can be cut and worked much more easily than metals. Saws and tools for softer metals like brass seem most satisfactory. Lower tool speeds than for normal wood are desirable.	Similar to stabilized.

[1] Forest Products Laboratory compreg.

[2] Mech. Eng. 63(10)734 (1941).

TABLE 3–5.—*Moisture absorption and swelling on water immersion of dimensionally stabilized, parallel-laminated compreg and an unstabilized form of parallel-laminated compreg, both made from maple and containing approximately 30 percent resin. Specimens ⅞-inch long in fiber direction*

Time in Water	Moisture absorption		Swelling in thickness	
	Stabilized form	Unstabilized form	Stabilized form	Unstabilized form
Days	*Percent*	*Percent*	*Percent*	*Percent*
4	-------------	-------------	0. 7	3. 9
11	0. 8	5. 0	1. 5	8. 6
30	3. 7	20. 6	3. 7	19. 9
60	5. 6	22. 9	5. 4	21. 6

3.33. Combinations of Compressed and Uncompressed Wood. When veneer is treated with a dimension-stabilizing resin, it is possible to combine it with cured impreg or untreated veneer in a single assembly-and-compression operation so that the treated, uncured plies become compressed while the treated and cured plies or the untreated plies remain virtually uncompressed. This is possible because the resin-forming constituents within the cell walls of wood greatly plasticize the wood, prior to the setting of the resin, at hot-pressing temperatures. For example, treated spruce, Douglas-fir, and cottonwood will compress to about half their original thickness under a pressure of 250 pounds per square inch. The dry, untreated plies and the treated precured plies under these conditions will, in general, compress less than 10 percent. In this way plywood with hard, densified faces and a core of practically normal density can be made which has improved finish and superior mechanical, water-resistant, and decay-resistant properties.

By this same technique, compreg can be made up with only partially compressed faces of either impreg or ordinary wood. These, in turn, can be glued as described under the heading "Impreg."

No extensive tests have as yet been made on the various combinations of these materials.

Plywood with either impreg or stabilized compreg faces on untreated cores showed weather-resistance properties almost as good as those of the impreg and compreg alone. Thermal cycles and water soaking and drying cycles did not break the bond between the dissimilar materials when made by the recommended methods.

Decay tests at the Forest Products Laboratory on plywood with impreg faces on ordinary wood cores indicated that when the cores were exposed they were subject to attack by both fungus and termites. When the edges were protected by dipping the assembled panels in a phenolic-resin glue diluted slightly with alcohol, decay of the cores was reduced.

No strength tests have as yet been made. It should be possible, however, to estimate the values of the combined materials from the properties and distribution of the component parts.

3.34. Possible Uses for Impreg and Compreg. Because of the improved properties of these two materials over ordinary wood, they show promise for a number of aeronautical uses.

Plywood with either impreg or thin stabilized compreg faces might be used to advantage for various skin surfaces because of its improved dimensional stability, decay resistance, and natural finish. Such superior skin surfaces are already being used on various control parts to some extent by one aircraft company. Because of the fact that veneer treated with a stabilizing resin is more plastic at hot-pressing temperatures than ordinary plywood, it may have definite advantages for molding by rubber-pad and bag-molding processes.

The use of impreg and stabilized compreg in the making of housings for sensitive electrical control equipment looks promising because of the low electrical conductivity of impreg in contrast to ordinary wood at high relative humidities.

Compreg shows promise for use as a die mold material; for spar plates; for various fastenings which can be improved by the use of a material with greater tensile, compressive, and shear strengths than those of normal wood; for the shanks of airplane propellers and even for the entire blade; for landing wheels, nonstructural controls, chart cases, etc. All the enumerated possible uses are now being investigated.

The compreg use that has been carried farthest is that for airplane propellers. The less dimensionally stable forms of compreg have been extensively used for the shanks of airplane propellers in Europe. Recently, two different complete compreg blades carved from blanks and one molded complete stabilized compreg ground-test blade have been approved by the Army and are now in production. The molded blade was made from resin-treated, uncompressed, uncured blanks of wood, the plies of which were assembled with a phenolic glue under conditions such that the glue set only partially. These were carved to the desired width and shape, but with a thickness 1½ to 2½ times that of the finished product. When the carved blanks, which had been balanced in the uncompressed form, were heated and compressed in a mold, the bonding glue was replasticized, and bonded the treated plies together after they were compressed to the final dimensions to produce a joint stronger than the wood. The chief advantages of this process are that the wood is more readily carved in the uncompressed, uncured state, and less wood and resin are wasted. This general procedure is also being commercially applied to the molding of aerial masts, and could be applied to a great number of different articles.

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3.4. HEAT-STABILIZED, COMPRESSED WOOD (STAYPAK).

3.40. General. Ordinary densified wood, which is made by compressing heated wood, usually in the form of sheets of veneer coated with a synthetic-resin bonding agent, has excellent strength properties. It tends, however, to return to its original uncompressed state when subjected to swelling conditions, recovering 50 to 60 percent of the bulk lost in compression. This material is customarily made of veneer conditioned to about 6 percent moisture content and is compressed at about 300° F. under pressures ranging from 2,000 to 3,000 pounds per square inch.

The Forest Products Laboratory has shown that, by increasing the original moisture content of the veneer to 9 to 12 percent and the temperature to 350° F., a material is produced which, when soaked in water, recovers only about 5 to 10 percent of the bulk lost under compression. The Laboratory has termed this product "staypak." This large reduction is presumably due to the fact that the lignin of the wood flows sufficiently under these conditions to relieve the internal stresses caused by the compression. Because of the higher moisture content, the wood is more plastic when under compression and hence can be compressed to a specific gravity of 1.38 at pressures of 1,500 to 1,800 pounds per square inch.

Heat-stabilized, compressed wood is darker in color than normal densified wood. Although the equilibrium swelling has not been materially reduced, swelling occurs so slowly, due to the tendency of the material to remain compressed, that it will readily meet the water-adsorption requirements of the Army Air Forces Specification for Compreg, No. 15065.

The strength properties of heat-stabilized, compressed wood, except for shear at right angles to the direction of compression, are equal to or higher than those of compreg. The property that is improved to the greatest extent is the impact strength. Heat-stabilized, compressed wood made at the Forest Products Laboratory from birch, maple, cottonwood, and sweetgum had Izod values ranging from 10 to 14 foot-pounds per inch of notch in contrast to values for compreg ranging from 3 to 8 foot-pounds per inch of notch. The average modulus of rupture for the four species was 37,000 pounds per square inch (Army Air Forces Specification No. 15065 for compreg requires 35,000), and the average modulus of elasticity in bending was 4,100,000 pounds per square inch (Army Air Forces Specification No. 15065 for compreg requires 2,700,000). The average compressive strength parallel to the grain for the four species was 20,200 pounds per square inch, which just exceeds the Army Air Forces Specification for compreg. The shearing strength parallel to the grain and in the direction of compression of the wood will readily meet the Army Air Forces Specification of 5,000 pounds per square inch, using the cylindrical double-shear test. Of the four species investigated, maple alone gave shear values parallel to the grain and at right angles to the direction of compression that would consistently meet the specifications. Values as low as 2,000 pounds per square inch (half of the values specified for compreg) were obtained with cottonwood and sweetgum. Birch gives border-line values.

Heat-stabilized, compressed wood can be made from solid wood as well as from veneer, thus avoiding the use of critical resins. The properties, as determined in limited tests, appear to be similar to those for the material made from veneer.

Heat-stabilized, compressed wood is easier to glue than stabilized compreg, because it has no glossy, resinous surface and absorbs solvents somewhat better. Excellent joints were obtained in tests with several different synthetic resin glues.

Experiments are under way in an attempt to substitute heat-stabilized, compressed wood made from maple or birch for unstabilized forms of compreg and, in some instances, for stabilized compreg. Tests are also under way to determine its suitability for propellers. For uses where the shear at right angles to the direction of compression is not highly critical, heat-stabilized wood made from the less critical species may be suitable.

3.5. HIGH-STRENGTH LAMINATED PAPER PLASTIC (PAPREG).

3.50. General. Papreg is a laminated paper plastic of high tensile strength and high modulus of elasticity developed at the Forest Products Laboratory. It can be made to have more than twice the tensile strength and more than one and one-half times the modulus of elasticity of the best conventional paper laminates. The plastic can be produced under low molding pressures and therefore has possibilities of use in large applications such as monocoque aircraft construction.

Papreg is composed of laminations of special papers impregnated and molded with phenol-formaldehyde resins. The pulps that have been found suitable are those in which the wood has been digested just sufficiently to produce a well-fiberized pulp. The paper is made with high tensile strength in at least one direction, high density, and high absorbency. The highest tensile strength in the plastic is obtained when the paper is parallel laminated; that is, with the sheets laid parallel in the direction of their highest tensile strength. The tensile strength and modulus of elasticity in tension of cross-laminated plastic are about 80 percent of those properties in parallel-laminated plastic (tested in the grain direction). Parallel-laminated plastic is, of course, highly anisotropic, whereas the cross-laminated material is more nearly isotropic and, for this reason, may be better adapted to some applications.

The minimum requirements (Federal Specification L–P–406, Organic Plastics) for parallel-laminated papreg, tested in the grain (fiber) direction, are a tensile strength of 35,000 pounds per square inch and a modulus of elasticity in tension of 3,000,000 pounds per square inch. The specific gravity is about 1.4 and the water absorption 2 to 5 percent. In general, the strength values, with respect to normal temperature, range from an increase of about 15 percent at −65° F. to a decrease of about 20 percent at 158° F. Although the smooth surface does not require the involved finishing and coating that metal and wood need, a low-gloss, highly pigmented surface can be readily obtained, if desired, by incorporating the pigment in the resin used in impregnating the surface laminations. The moisture and decay resistance are reasonably acceptable.

Papreg can be molded in moderate double curvature forms without special treatment. Slight taper and gage variations are readily fabricated to produce members of uniform strength, as in cantilever beams. The material is subject to die and bag molding at pressures as low as 75 pounds per square inch. L-sections with an internal radius of curvature as low as one-sixteenth inch have been bag-molded with no loss in strength in the bent zone. Partially precured panels can be laid up and molded like veneer by bag-molding methods. High-strength tubes have been made under conditions such that the wrapping pressure was sufficient for molding. Papreg can be satisfactorily glued by a number of cold-setting, low-temperature, and hot-press glues.

For data on the strength and related properties of papreg, see Forest Products Laboratory Restricted Mimeograph No. 1319.

3.6. COMBINATION MATERIALS.

3.60. General. Combinations achieved by gluing together low- and high-density materials such as balsa with plywood, and plywood, balsa, or other low-density materials with compreg, papreg, and impreg, result in products with special characteristics which are useful in aircraft.

Such combinations may be achieved as flat or curved panels by bonding between platens of a hydraulic press, molding with fluid pressure, or pressing by other conventional methods. There is no fixed relationship between the position of the high- and low-density layers in any combination. A common practice is to employ thin, high-density layers on the surface and a relatively thick, low-density material in the center of a panel (commonly referred to as sandwich construction), but this is only one of several possible arrangements, and others will probably be developed to meet specific requirements in the future.

The combination may be achieved by bonding the materials with either hot- or cold-setting glues, depending upon the exposure, types of material, and methods of fabrication.

Papreg can be formed from resin-impregnated paper by hot-pressing in the same operation during which it is bonded to the lower density core. For example, an assembly consisting of sheets of veneer with glue between and layers of uncured resin-impregnated paper on top and bottom can be subjected to heat and pressure so that, when withdrawn from the press, it will be in the form of a plywood panel surfaced with papreg.

CHAPTER 4. AIRCRAFT GLUES

4.0. KINDS.

4.00. General. Synthetic-resin and casein glues are the two kinds of glue now in use for aircraft gluing. Animal glue and blood-albumin glue were formerly used to some extent but are no longer employed.

4.01. Synthetic-resin Glues. The development of synthetic-resin glues for wood (*4–5*) has provided bonding materials superior in a number of important properties to those formerly used in aircraft. Most uses in aircraft require glues that retain their strength and durability under moist conditions and even after exposure to water. In these properties the synthetic-resin glues are outstanding (*4–2*, *4–3*).

The best-known and most commonly used synthetic-resin glues are the phenol-formaldehyde and urea-formaldehyde types. There are also synthetic-resin adhesives of the melamine, resorcinol, and polyvinyl ester type, but they are not yet so widely used. Some of these resins may be combined with each other or with other materials to form glues of somewhat different basic characteristics than those made from a single resin if such materials are compatible. Examples of such combinations are urea and melamine, urea and resorcinol, phenol and resorcinol, and phenol and dried blood. Insoluble materials, such as walnut-shell flour or wood flour, are often added to the resins to give better working characteristics and joint forming properties. As a result of this practice, there are resin glues containing varying amounts of other materials, some of which are variously referred to as "fortified," "modified," or "extended."

Synthetic-resin glues may be classified as thermosetting or thermoplastic. The phenol, urea, melamine, and resorcinol resins belong to the thermosetting class, and once the condensation reaction, which is hastened by heating, is complete, no subsequent softening occurs even though the temperature is increased beyond the original setting temperature. Synthetic resins of the thermoplastic class, such as the vinyl acetate or butyrate, soften whenever the temperature is raised above the softening range that is characteristic of each particular type of resin. A thermoplastic resin must be first heated and then cooled under pressure in using it as an adhesive. Glues of the strictly thermoplastic type are not recommended for the gluing of wood aircraft parts.

Variations in the raw materials, the details of processing, and added materials, such as catalysts and fillers, produce synthetic-resin glues of different characteristics, form, and properties. There are thus a number of resin glues available of varying use characteristics. A common characteristic of the thermosetting resin glues is that they are only partly "polymerized" during manufacture and a further reaction is necessary to set or "cure" them.

Synthetic-resin glues may be marketed in the form of dry film, dry powder, suspension in water, or nonaqueous solution. A number of them are formulated for hot pressing, during which the high temperatures soften the resin to an adhesive condition and complete the setting reaction. Cold-setting resins now in common use are mainly of the urea-resin type and contain a catalyst which accelerates the chemical reaction and results in the setting of the glue at ordinary room temperatures. Other resin glues, which set at intermediate temperatures, are formulated from phenols, melamines, or combinations of resins. Considerable progress has been made toward the development of phenol, resorcinol, and melamine type glues that will set at somewhat lower temperatures, the aim being the perfection of glues that will set at room temperature or slightly above and which will be more durable than the present cold-setting resins and casein glues.

4.02. Casein Glues. The forms, characteristics, and properties of water-resistant casein glues have remained substantially the same for many years except for the addition of preservatives (*4–6*). The dried casein of milk is the basic constitutent of this class of glues. It is combined with alkalies or alkali-producing chemicals which, when mixed with water, dissolve the casein. The addition of lime or other materials causes the glue to set and later retain a part of its strength, even when saturated with water. Casein glues for use in aircraft should contain suitable preservatives to make the set glue resistant to molds and other deteriorating organisms.

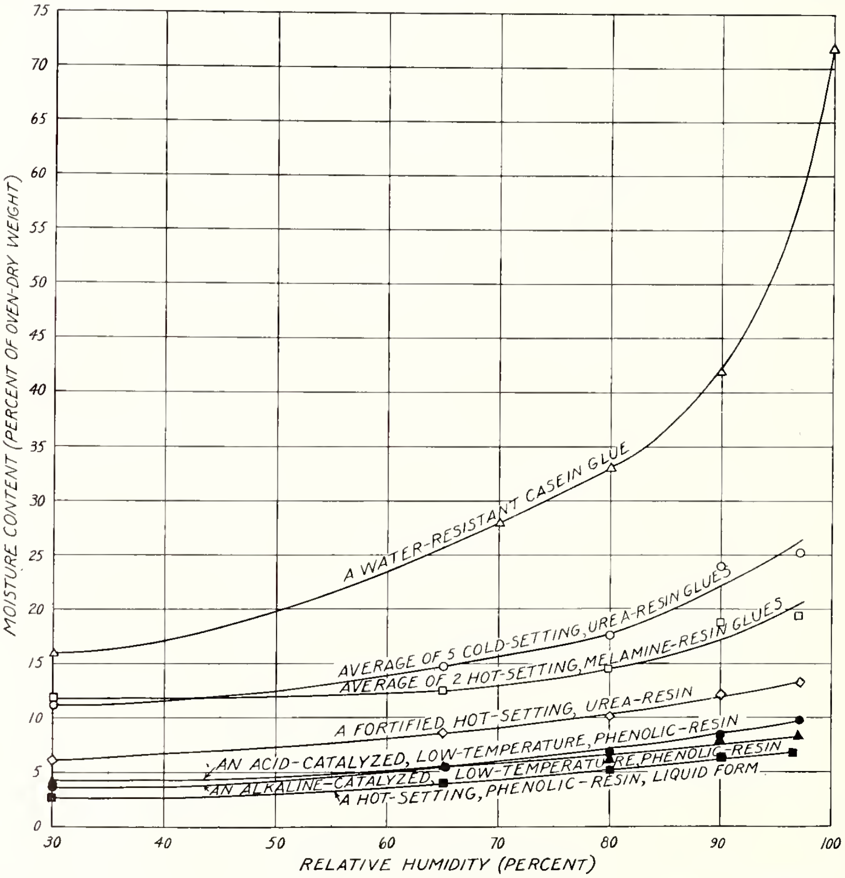

FIGURE 4-1.—Approximate equilibrium moisture content of cured glue films at various relative humidities at 80° F.

Most casein glues are sold in powder form ready to be mixed with water. They are mixed and applied at ordinary room temperatures. Casein glues are used much in aircraft repair and to some extent in assembly gluing, but have been largely replaced in original fabrication of aircraft parts by synthetic-resin glues that set at low temperatures. They have been in use for many years and the details of their preparations and application are generally well known (*4–8*).

4.1. PROPERTIES OF AIRCRAFT GLUES.

4.10. General. The properties of the glues used in aircraft construction vary widely. Specific information on these properties has been obtained at the Forest Products Laboratory in large part from tests of joints and wood assemblies. It is difficult to interpret the various properties of glues as dry films or solids in terms of their properties and performance in wood joints. The data herein presented on properties of glues are accordingly based mainly on joint and assembly tests.

4.11. Resistance of Glues to Moisture and Temperature Effects. The tendency of glues to absorb moisture from the atmosphere is usually associated with their wet strength or water resistance. Figure 4–1 shows the approximate moisture equilibrium of the films of several types of glues when exposed at 80° F. to different relative humidities. These data are in general related to the strength of the glues in wood joints, in that those glues having a high moisture equilibrium are normally low in wet strength.

4.12. Effect of Moisture on Glues. The resistance of different types of synthetic-resin glues and of casein glue, without toxics, in plywood joints after exposure to severe moisture and temperature conditions, is illustrated in figures 4–2, 4–3, and 4–4. The plywood was made of 3 plies of $\frac{1}{16}$-inch birch veneer. The glues were prepared and applied in accordance with manufacturers' directions. The plywood after pressing was conditioned to equilibrium with a relative humidity of 65 percent and 80° F. temperature and then cut into shear specimens. A part of the specimens from each panel were tested dry and a part wet after soaking in water at room temperatures for 48 hours. The remaining specimens were divided into groups, subjected to prolonged exposure at different conditions, and tested at various intervals during exposure. The joint strengths of the specimens, tested dry after various exposure periods, are shown as percentages of the original dry strength. Specimens subjected to cyclic exposures involving moisture were tested after the dry portion of the cycle. The estimated percentages of wood failure in the tested specimens are shown as vertical bars in each graph.

Figure 4–2 shows the results obtained after exposure of the plywood specimens to a repeating cycle consisting of 2 weeks at 97 percent relative humidity and 80° F. and 2 weeks at 30 percent relative humidity and 80° F. Of the five types of glues involved, only the phenol-formaldehyde retained most of its original strength under prolonged exposure, and the uniformly high wood failure in the tested joints throughout the 6-year exposure indicates that the glue had not deteriorated more rapidly than the wood. In all the other types of glues used, the declining wood failure with exposure indicates a more rapid deterioration in the glue than in the wood.

Other specimens from the same plywood panels were tested after exposure to (1) a repeating cycle of 2 days' soaking in water at room temperatures and 12 days' drying at 30 percent relative humidity and 80° F. (fig. 4–4), (2) continuous 97 percent relative humidity and 80° F., and (3) continuous soaking in water at room temperatures. The order of the five types of glues with respect to durability under these three exposures was approximately the same as that shown for alternate high- and low-humidity exposure in figure 4–2. In the continuous soaking and the alternate soaking and drying exposures, the plywood glued with urea resins showed less rapid deterioration than in the high-humidity exposures. The casein glues likewise withstood continuous soaking and alternate soaking and drying exposures somewhat better than continuous or cyclic exposures to high humidities. Continuous exposure to 97 percent relative humidity weakened the casein glue without toxic more rapidly and the urea-resin glues at about the same rate as the cycle of high and low humidity (fig. 4–2). The vinyl-ester or thermoplastic-glued plywood was weakened more rapidly in the continuous soaking tests than in the high-humidity exposures and more rapidly in cycles involving wetting and drying than in exposures to continuous high humidity or soaking. The declining strength of all

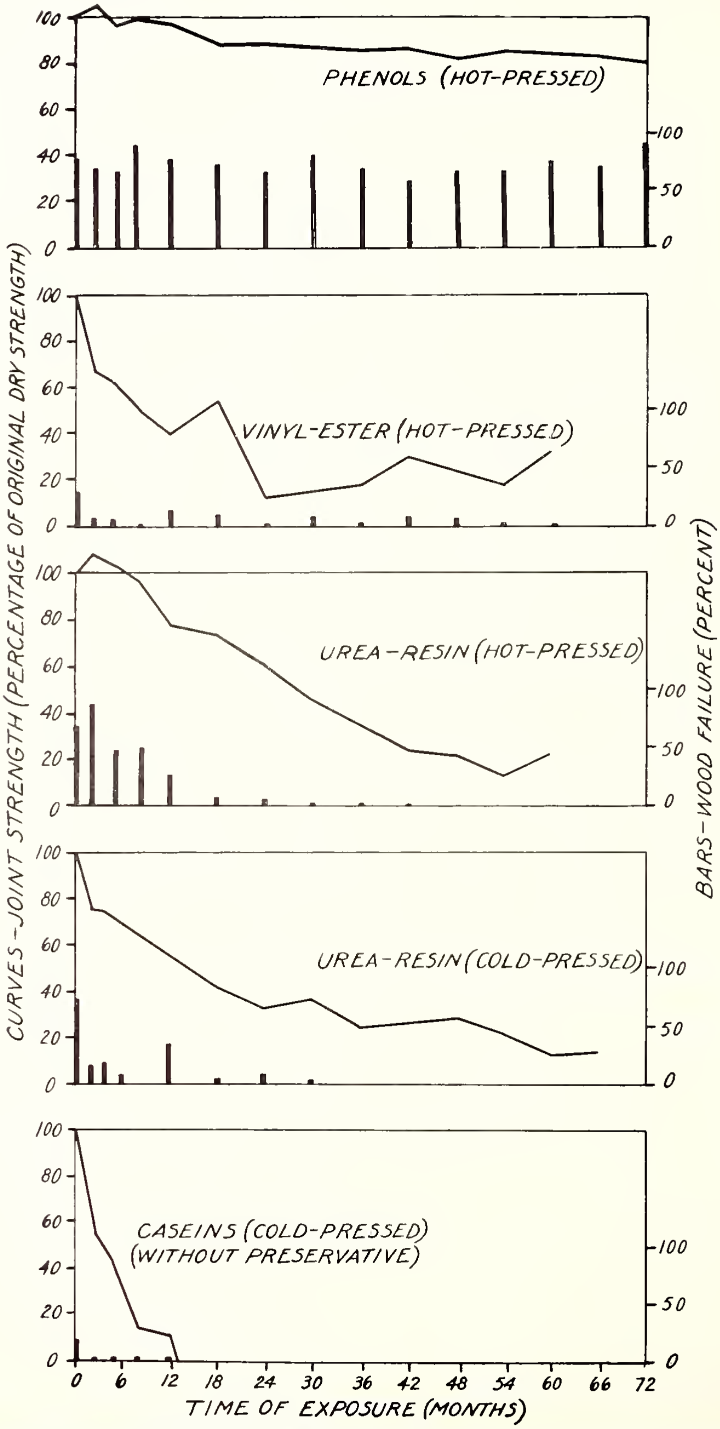

FIGURE 4-2.—Resistance of plywood, glued with 5 types of glues, when exposed to a repeating cycle consisting of 2 weeks in 97 percent relative humidity and 80° F., followed by 2 weeks in 30 percent relative humidity and 80° F.

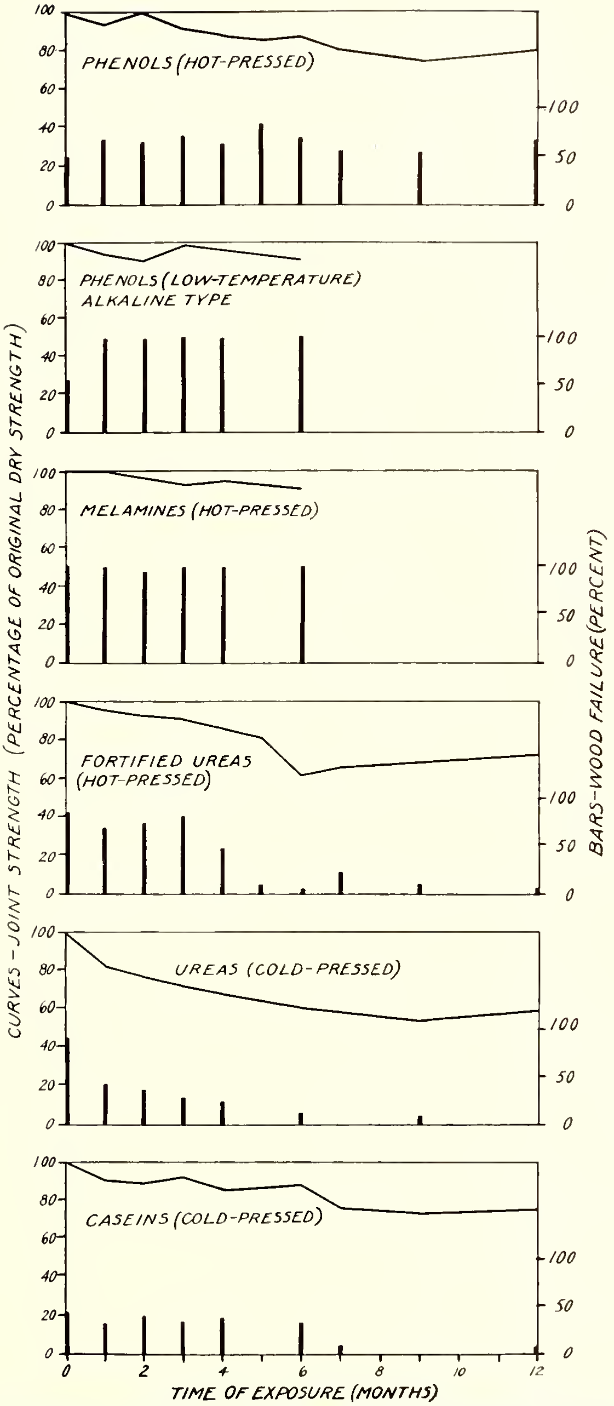

FIGURE 4-3.—Resistance of plywood, glued with 6 types of glues, when exposed to a repeating cycle consisting of 8 hours at 158° F. and 20 percent relative humidity, followed by 16 hours at 80° F. and 65 percent relative humidity.

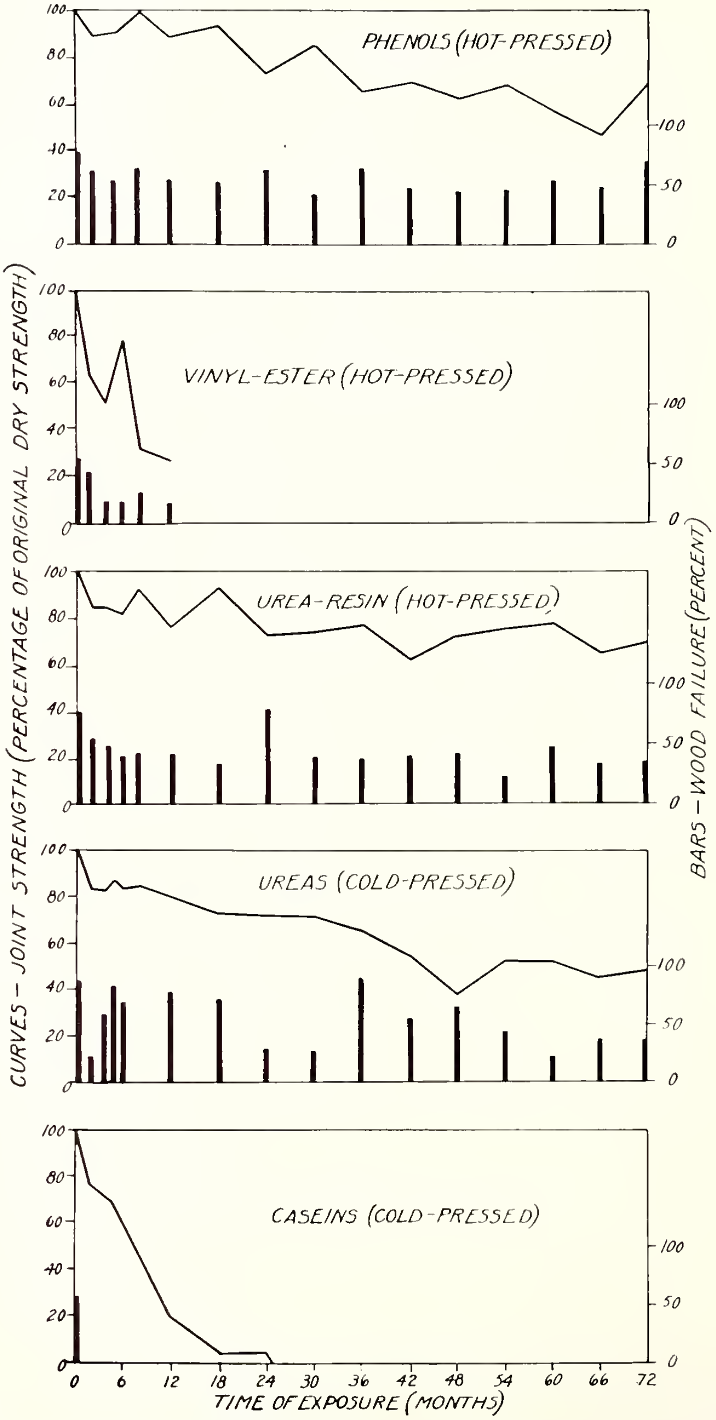

FIGURE 4-4.—Resistance of plywood, glued with 5 types of glues, when exposed to a repeating cycle of 2 days' soaking in water at room temperatures and 12 days' drying at 30 percent relative humidity and 80° F.

glues, except phenol-formaldehyde, was associated with rapidly declining wood failure in all the exposures.

4.13. Effect of Temperatures on Glues. Figure 4–3 shows the results obtained after exposure of plywood specimens glued with six types of glues to a repeating cycle consisting of 8 hours at 158° F. and 20 percent relative humidity and 16 hours at 80° F. and 65 percent relative humidity. The plywood was of the same type and was prepared and tested after exposure as described in section 4.12. The joint strengths at various test periods are again shown as percentages of the original dry strength, and the estimated percentages of wood failure in the tested specimens are shown as vertical bars in each graph.

The six types of glues shown in figure 4–3 represent three that were included in figure 4–2 and three additional types, namely, low-temperature phenol, hot-pressed melamine, and fortified urea (hot-pressed). The three types shown in both figures are: high-temperature phenol, cold-setting urea, and casein. The cold-setting urea resins of figure 4–3 met the requirements of Army-Navy Aeronautical Specification AN–G–8, whereas those in figure 4–2 may or may not have met its requirements.

Cold-pressed ureas showed the largest decline in strength, dropping to approximately one-half their original dry strength during 9 months' exposure, and the decline in strength was associated with a reduction in wood failure, thereby indicating that the glue was affected more than the wood. The high- and low-temperature phenols, melamine, and casein glue, all showed a small reduction in dry strength—a 10- to 15-percent drop in 6 months' time—but the percentages of wood failure were maintained, indicating that the small reduction in strength may be associated with factors other than the deterioration of the glue. The decline in strength of the fortified ureas was not as rapid as that of the cold-setting ureas.

Similar plywood specimens glued with the six types of glues shown in figure 4–3 were also exposed to three other temperature conditions: (1) continuous exposure to 158° F. and 20 percent relative humidity, (2) continuous exposure to 158° F. and 60 percent relative humidity, and (3) a cycle of 8 hours at −67° F. over dry ice and 16 hours at 80° F. and 65 percent relative humidity. When exposed continuously to 158° F., the cold-pressed urea resins weakened even more rapidly than shown in figure 4–3, and the decline in strength was more pronounced at 158° F. with 60 percent relative humidity than at 158° F. with 20 percent relative humidity. The casein, phenol, and melamine resins showed only a moderate decline in strength at the continuous high temperature exposures, while the effect on the fortified urea resin was more marked than is shown in figure 4–3. The exposure to the cycle involving a temperature of −67° F. showed no weakening effect on any of the six types of glues, and in most cases there was an increase in strength under exposures up to 6 months' time.

4.14. Casein Glues with Preservatives. The test results shown in figures 4–2 to 4–4 for casein glue were obtained with an adhesive that contained no preservatives. Results of tests on casein glues containing suitable preservatives, however, show a marked improvement in durability under exposure to high humidity. Figure 4–5 shows the results of tests on casein glues containing two such preservatives, beta naphthol and creosote. It should be pointed out in connection with the results shown in figure 4–5 that by the end of 20 months considerable decay had developed in the wood of all shear specimens. Consequently, measurements made at longer exposure periods were more a measure of wood than of glue-joint quality. More recently developed preservatives, such as the chlorinated phenols and their sodium salts, show even higher effectiveness in preventing organic deterioration of casein glues under high humidity exposures, which are especially favorable for the growth of molds (*4-4*). The improvement in mold resistance obtainable with preservatives such as pentachlorophenol is illustrated by the results shown in figure 4–6. These tests on plywood have not run long enough to determine the maximum period under high humidity exposures for which pentachlorophenol and similarly effective preservatives will provide protection against molds and other forms of organic deterioration. Further evidence on the effectiveness of pentachlorophenol as a casein glue preservative is furnished, however, by the results of the tests on laminated timbers (sec. 4.15). The addition of preservatives does not appear to measurably affect the water resistance of casein glues.

4.15. Exposure Tests on Laminated Beams. Results of tests on laminated beams exposed to high humidity and to the weather without protection confirm in general the order of durability of casein, phenol, and urea-resin glues as determined in plywood (sec. 4.14). Douglas-fir and southern yellow pine beams, 7 by 7 inches in cross section and 6 feet in length, and containing 9 laminations each, were glued

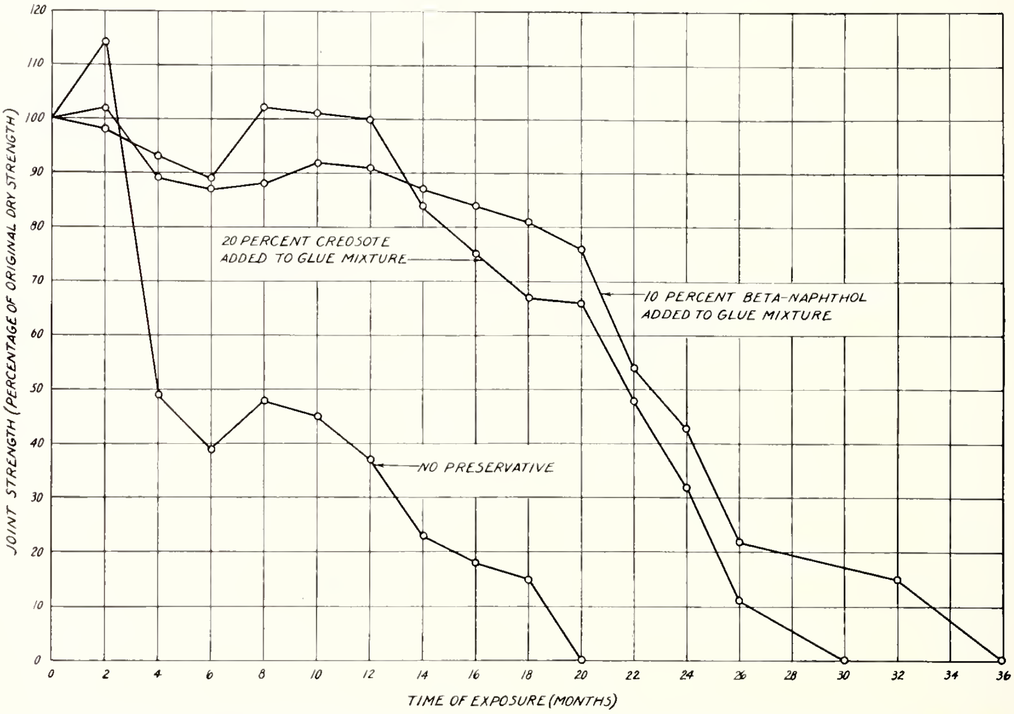

FIGURE 4-5.—Effect of preservatives in casein glue on durability of plywood joints exposed continuously to 95-99 percent relative humidity. Specimens tested upon removal from 95-99 percent humidity. Results for 2 glues averaged.

with a casein glue (without preservative); a casein glue with the addition of 10 percent of pentachlorophenol; a low-temperature, phenolic-resin glue (pressed cold and later heated in a kiln at 150° F.); and a cold-setting, urea-resin glue. The beams were subjected in groups to continuous 97 percent relative humidity and all but those glued with preservative-treated casein were exposed to weathering. Specimens from all joints of all beams were tested before the exposures started, and tests were made on specimens taken from both ends of the beams at intervals up to 30 months. One end of each otherwise unpainted beam was kept coated to simulate conditions in the center portion.

After 30 months of exposure, the joints made with the low-temperature phenol showed the highest joint strength and wood failure under both conditions of exposure. Under exposure to the high humidity, casein glue containing preservative showed almost as good results as the phenol but the casein without preservative had failed completely and the urea resin was severely weakened. Exposed to the weather, the urea-resin glue showed better performance than the casein glue without preservative. The continuous exposure to high relative humidity caused the casein without preservative and the urea-resin glues to weaken faster than did exposure to the weather.

4.16. Summary of Properties. The properties of set glues of the various types are summarized below on the basis of existing information.

4.160. Phenol-formaldehyde Glues. Phenolic-resin glues absorb less moisture from the air than does wood. Their strength in joints is equal to or greater than the strength of normal wood over wide ranges of moisture conditions and temperature. They are resistant to the attacks of micro-organisms and are highly durable under adverse exposure conditions. In general, well-made phenolic-resin joints are very difficult to destroy without destroying the wood itself.

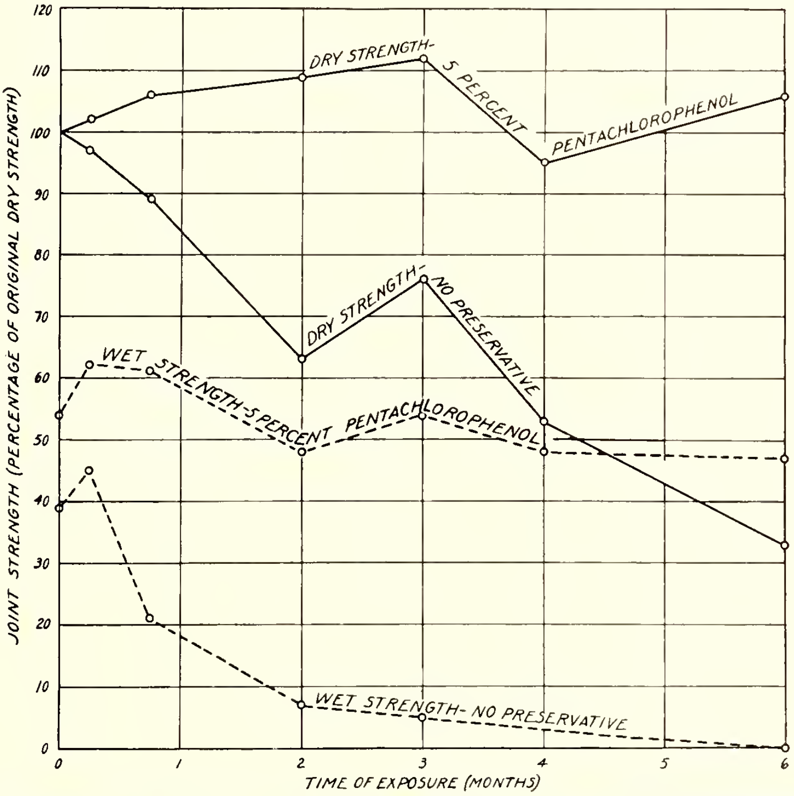

FIGURE 4-6.—Dry and wet strength of plywood joints, glued with casein glues containing 5 percent of pentachlorophenol, after exposure to 97 percent relative humidity. Dry tests made upon removal of specimens from 97 percent relative humidity, wet tests after soaking in water at room temperature for 48 hours. Results from 2 glues averaged.

Phenolic-resin glues may be either acid or alkaline in reaction. Hot-press phenolic glues are usually nearly neutral in reaction, but the low-temperature phenolic glues contain either acidic or alkaline catalysts. Less information is available about the properties of the low-temperature phenolics in joints, but available data indicate that they produce joints high in strength and in resistance to moisture and various temperatures, if properly cured. There are indications that highly acid phenols have an injurious effect on the wood and are less desirable in aircraft joints than the alkaline-catalyzed phenols.

4.161. Melamine Glues. Melamine glues appear to be similar to phenols in all essential properties.

4.162. Urea-formaldehyde Glues. Urea-formaldehyde glues are acid in reaction. When prepared for application, the cold-press urea resins are higher in acidity than the hot-press urea resins, inasmuch as additional catalyst is added to produce a setting reaction at normal room temperatures. Urea-resin glues generally absorb more moisture from the air than do phenolic-resin glues. Wood joints well made with urea-resin glues are high in dry and wet strength at ordinary temperatures. Urea-resin glue joints will not withstand prolonged exposures to high temperatures; pronounced weakening of the joints occurs when exposed to water above about 150° F. and a more gradual weakening occurs in dry air at 158° F. Joints made with urea-resin glue are less resistant under long exposure to dampness and to the weather than are joints made with phenolic-resin glues.

4.163. Casein Glues. Casein glues are highly alkaline in reaction, and absorb high percentages of moisture from the air. Joints well made with casein glues are high in dry strength but the wet strength of such joints when saturated with water is less than half their dry strength. Casein glues show moderate resistance to hot water and good resistance to high dry temperatures. Casein glues without preservatives are not durable when exposed to relative humidities of 90 percent and higher but the addition of preservatives of suitable kinds and amounts increases their durability under such conditions.

4.2. USE CHARACTERISTICS OF AIRCRAFT GLUES.

4.20. General. The various operations involved in the production of aircraft require glues of different use characteristics. Assembly gluing operations require a glue that makes strong joints under pressures obtainable by nail gluing and fluid pressures. In nail gluing the skin to the fuselage or wing frame, this low pressure requirement may be combined with a requirement for a moderately long assembly time. In bag-molding operations, a long assembly life is often required and yet the glue must be quite fluid at some time during the pressing period. Gluing large surfaces between rigid plates and cauls, such as wing beams and plywood, requires a glue that makes strong joints under high pressures needed to bring all surfaces into intimate contact, whereas bag molding with fluid pressures permits the use of glues of lower pressure characteristics. Many operations with existing equipment require cold-setting glues, while others permit the use of hot-setting glues. Fortunately, glues are available with characteristics that meet these various requirements reasonably well.

As an aid to the user of aircraft glues in the selection of glue types and brands of suitable characteristics and of those best adapted to specific operations, table 4–1 has been prepared. The compilation of use characteristics has been prepared largely from the glue manufacturers' directions and instructions, the experience of users of the glues, and such test results as are available. The list is perhaps incomplete and is subject to change as some brands of glues are discontinued, others are modified, and new glues are developed and marketed. The inclusion of any glue in this list does not constitute an endorsement or assurance that it will meet current specifications.

TABLE 4-1.—*Principal synthetic-resin glues classified as to type, form, and general operating characteristics* [1]

Designation (1)	Hardener or modifier (2)	Type [2] (3)	Form (4)	Solvent (5)	Approximate solids content mixed for use (6)	Working life at 75° F. (7)	Assembly time at 75° F. (8)	Curing temperature (9)	Favorable moisture content of wood (10)
					Percent			° *F.*	*Percent*
Amberlite [3] PR-14	Incorporated	Hot-press phenolic	Powder	Water, alcohol or both.	40-65	Several days	½ hour to many days.	240-320	6-15
Amberlite [4] PR-23	Incorporated	Hot-press phenolic	Powder	Water, alcohol or both.	70-80	7 days	1 hour to many days	280-350	8-12
Amberlite [5,6] PR-51	Incorporated; Q-107	Hot-press phenolic	Powder	Water or dilute caustic soda.	40-45	Over 8 hours	Up to 1 hour	240-320	0-5
Amberlite [4] PR-65	Incorporated	Hot-press	Powder	Water, acetone or both.	50-65	Several days	5 to 20 minutes	220-320	
Bakelite [6] XC-7381	Incorporated	Hot-press phenolic	Liquid	Alcohol	50	Over 8 hours	Up to several days	280-320	3-18
Bakelite BCU-12772	XK-16229	Cold-press urea	Liquid	Water	68	3 hours	Up to 20 minutes	Minimum 70	8-15
Bakelite [3] XC-13616	Incorporated	Hot-press phenolic	Liquid	Alcohol	50	Over 8 hours	Up to several days	260-300	2-10
Bakelite [3] XC-15811	Incorporated	Hot-press phenolic	Liquid	Alcohol	50	Over 8 hours	Up to several days	260-300	2-10
Bakelite [6] BC-16168	Incorporated	Hot-press phenolic	Powder	Water	50	Over 8 hours	Up to 24 hours	230-270	2-10
Bakelite [4] XC-16200	Incorporated	Hot-press phenolic	Powder	Alcohol and water	45	Over 8 hours	2-24 hours	200-240	
Bakelite [3] XCU-16257	XK-16228	Hot-press urea	Liquid	Acetone and water	66	5 hours	Up to 48 hours	180-250	6-15
Bakelite [3] XC-16529	Incorporated	Hot-press phenolic	Powder	Water or alcohol and water.	50	Over 8 hours	1 hour to 3 days	180-270	2-10
Beckamine P-378	Ammonium nitrate	Hot-press urea	Liquid	Water	67	4 hours	Up to 1 hour	250-260	2-12
Butacite 4639	None	Thermoplastic vinyl butyral.	Liquid	Alcohol	18-20	Indefinite	Many days	250-300	6-15
Butacite 4644	None	Thermoplastic vinyl butyral.	Liquid	Alcohol	18-20	Indefinite	Many days	250-300	6-15
Cascamite ANS	Incorporated	Cold-press urea	Powder	Water	65	4 hours	Up to 20 minutes	Minimum 70	6-15
Cascamite [3,7] BG-2	H-21	Hot-press fortified urea.	Powder	Water	71	Over 8 hours	Up to 7 days	220-300	6-15
Cascamite QS-1	Incorporated	Cold-press urea	Powder	Water	67	3 hours	Up to 15 minutes	Minimum 70	6-15
Cascamite 66	M-16	Cold-press urea	Powder	Water	65	4 hours	Up to 20 minutes	Minimum 70	6-15
Cascamite [6] 66	H-19	Hot-press fortified urea.	Powder	Water	71	Over 8 hours	Up to 4 hours	260	4-12
Casco Resin Liquid No. 5.	FM-50	Cold-press urea	Liquid	Water	64	4 hours	Up to 20 minutes	Minimum 70	6-15
Cascophen [3] BG-17	H-23	Hot-press phenolic	Liquid	Water	50	Several days	15 minutes to 4 days	220-300	6-12
Cascophen [3,7] BG-P-15.	Incorporated	Hot-press phenolic	Powder	Water	50	Several days	30 minutes to 7 days	240-300	6-12
Cascophen LT-67	M-18	Low-temperature phenolic.	Liquid	Water	71	4 to 5 hours	Up to 1¼ hours	150-200	8-15
Cascophen [6] P-48	Incorporated	Hot-press phenolic	Powder	Water	50	Several days	30 minutes to 7 days	260-300	6-12
Catabond 590	No. 1	Low-temperature phenolic.	Liquid	Alcohol	62	2 hours	Up to 20 minutes	150-200	2-12
Catabond 590	No. 7	Low-temperature phenolic.	Liquid	Alcohol	62	2 hours	15 to 60 minutes	150-200	2-12
Catabond [3] 591	No. 3	Hot-press phenolic	Liquid	Alcohol	62	Over 8 hours	Several days	300-320	6-15
Du Pont 4624	Incorporated	Modified vinyl	Liquid	Alcohol and water	20	Indefinite	Many days	250-300	3-18
Durez [5,6] 192	Incorporated	Hot-press phenolic	Powder	Water	40	24 hours	Up to 30 minutes	255-270	1-4
Durez [3] 194	Incorporated	Hot-press phenolic	Powder	Water	65-70	Over 24 hours	1 hour to 9 days	230-300	3-11
Durez 12041	7422	Low-temperature phenolic.	Liquid	Alcohol	67	7 hours	Up to 2 hours	150-200	2-12
Lauxite [5,6] PF-4	PF-4A	Hot-press phenolic	Liquid	Water		24 hours	½ to 24 hours	280	1-5
Lauxite PF-10	Incorporated	Hot-press phenolic	Powder	Water	63	Over 16 hours	½ to 48 hours	260-280	6-12

See footnotes at end of table.

TABLE 4–1.—*Principal synthetic-resin glues classified as to type, form, and general operating characteristics* [1]—Continued

Designation (1)	Hardener or modifier (2)	Type [2] (3)	Form (4)	Solvent (5)	Approximate solids content mixed for use (6)	Working life at 75° F. (7)	Assembly time at 75° F. (8)	Curing temperature (9)	Favorable moisture content of wood (10)
					Percent			° *F.*	*Percent*
Lauxite 9–2C	Incorporated	Hot-press urea	Powder	Water	63	Over 16 hours	Up to 48 hours	220–260	6–12
Lauxite 9–2C	250–L	Hot-press melamine-urea.	Powder	Water	63	Over 8 hours	Up to several hours	220–260	6–12
Lauxite 77X	Incorporated	Cold-press urea	Powder	Water	60	4 hours	Up to 20 minutes	Minimum 70	6–15
Lauxite 220	220 hardener	Cold-press urea	Liquid	Water	70	4 hours	Up to 20 minutes	Minimum 70	8–12
Lauxite 251	Incorporated	Hot-press melamine-urea.	Powder	Water	67	Several days	15 minutes to 24 hours.	190–300	1–8
Lauxite 252		Low-temperature melamine.	Powder	Water	67	4 hours	5 to 30 minutes	110 and up	8–12
Lauxite [3] 260	Incorporated	Hot-press melamine-urea.	Powder	Water	63	Over 16 hours	15 minutes to 24 hours.	190–300	1–8
Lauxite 947 MX	X and Y	Cold-press urea	Powder	Water	60	2 to 5 hours	Up to 20 minutes	Minimum 70	6–15
Le Page's Aquatite	X–59	Cold-press urea	Liquid	Water	52	4 to 5 hours	Up to 20 minutes	Minimum 70	6–15
Le Page's Panite	Incorporated	Cold-press urea	Powder	Water	65	4 hours	Up to 20 minutes	Minimum 70	6–15
Melurac [3] 300	Incorporated	Hot-press melamine-urea.	Powder	Water	60	10 to 12 hours	Up to 7 days	200–240	8–12
Melmac [3] 400	Incorporated	Hot-press melamine	Powder	Water	60	36 hours	Up to 30 days	190–240	8–12
Melmac [3] 401	Incorporated	Hot-press melamine	Powder	Water	67	36 hours	Up to 30 days	190–240	8–12
Penacolite G1124	G1124B	Low-temperature resorcinol.	Liquid	Water and alcohol	59	2 to 3 hours	Up to 45 minutes	75–100	4–12
Perkins L–100	S-121	Cold-press urea	Liquid	Water	65–70	2½ hours	Up to 20 minutes	Minimum 70	8–12
Perkins D–111	C–23	Cold-press urea	Powder	Water	60–65	5 hours	Up to 20 minutes	Minimum 70	8–12
Perkins DC–246	Incorporated	Cold-press urea	Powder	Water	60–65	5 hours	Up to 20 minutes	Minimum 70	8–12
Perkins M–411	C–23	Low temperature melamine-urea.	Powder	Water	62	6 hours	Up to 20 minutes	140–160	8–12
Perkins M–411	HC–26	Hot-press melamine-urea.	Powder	Water	62	8 hours	10 minutes to 8 hours.	260	6–9
Perkins M–411	Incorporated	Low-temperature or hot-press melamine-urea.	Powder	Water	62–64	Over 24 hours	10 minutes to 48 hours.	140–310	6–12
Plaskon 107–2	B–7	Hot-press urea	Powder	Water	64	Over 8 hours	Up to 48 hours	220–240	6–12
Plaskon 201–2	A	Cold-press urea	Powder	Water	61	4 hours	Up to 20 minutes	Minimum 70	6–15
Plaskon 201–2	D	Low-temperature fortified urea.	Powder	Water	65	Over 8 hours	Up to 20 minutes	140	6–15
Plaskon 250–2	Incorporated	Cold-press urea	Powder	Water	60	4 hours	Up to 20 minutes	Minimum 70	6–15
Plaskon [3] [7] 700–2	B	Hot-press fortified urea.	Powder	Water	78	Not over 8 hours.	Up to 72 hours	200–250	6–12
Plyophen [5] [6] 508–C	Incorporated	Hot-press phenolic	Liquid	Water	43	8 hours	Up to 2 hours	260–270	2–12
Resinox [5] 200	Incorporated	Hot-press phenolic	Powder	Water, alcohol, or both.	40–60	24 hours	Up to 2 hours	240–270	2–10
Resinox [3] 210	Incorporated	Hot-press phenolic	Powder	Water, alcohol, or both.	40–60	24 hours	Up to several days	260–320	6–15
Resinox 230	B	Low-temperature phenolic.	Liquid	Water	75	4 to 5 hours	Up to 60 minutes	150–200	6–15
Resinox [3] 840	Incorporated	Hot-press melamine	Powder	Water	60–70	8 to 10 hours	Up to 10 days	220–300	6–15
Resinox [3] 841	Incorporated	Hot-press melamine	Film	None	100	Several months.	Up to several months.	220–300	8–14
Tego [3] 2	Incorporated	Hot-press phenolic	Film	None	100	Several months.	Up to several months.	280–320	8–12

Textolite 2163	2775	Low - temperature pbenolic.	Liquid	Alcohol	85	5 hours	Up to 30 minutes	150-200	2-12
Textolite 2168	2777	Hot-press melamine —urea.	Liquid	Water	75	15 to 20 hours	Up to 1 hour	212-265	6-12
Uformite 430	R	Cold-press urea	Liquid	Water	70	1 hour	Up to 15 minutes	Minimum 70	6-15
Uformite 430	Y	Hot-press urea	Liquid	Water	70	24 hours	5 to 30 minutes	240	6-15
Uformite [3] 430	Q-107 and Q-87	Low-temperature or hot-press fortified urea.	Liquid	Water	75	4 to 24 hours	Up to 4 days	140-300	6-15
Uformite 500	R	Cold-press urea	Powder	Water	70	1 hour	Up to 15 minutes	Minimum 70	6-15
Uformite 500	Y	Hot-press urea	Powder	Water	70	24 bours	5 to 30 minutes	240	6-15
Uformite [3] 500	Q-107 and Q-87	Low-temperature or hot-press fortified urea.	Powder	Water	75	4 to 24 hours	Up to 4 days	140-300	6-15
Uformite CB-551	Incorporated	Cold-press urea	Powder	Water	70	3 to 4 bours	Up to 20 minutes	Minimum 70	6-15
Urac 101	Incorporated	Cold-press urea	Powder	Water	60	4 to 5 hours	Up to 20 minutes	Minimum 70	6-15
Urac 180	59	Cold-press urea	Liquid	Water	70	4 to 5 hours	Up to 20 minutes	Minimum 70	6-15
Vinylite XYNC	None	Thermoplastic vinyl butyral.	Liquid	Alcobol and methyl acetate.	16-18	Indefinite	Many days	200-320	6-15
Vinylseal MA-28-18	None	Thermoplastic modified vinyl acetate.	Liquid	Alcohol and metbyl acetate.	12-16	Indenfiite	Many days	200-320	6-15
Weldwood	Incorporated	Cold-press urea	Powder	Water	60	3 hours	Up to 20 minutes	Minimum 70	6-15

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[1] Information contained in this table is based on data supplied in part by the glue manufacturers, in part by the users, and in part by the Forest Products Laboratory. Tbe listing of glues in this table is not a recommendation of quality or indication that they meet current specifications for aircraft use. The limits given for curing temperatures and other details, have not, in general, been verified by tests at the Forest Products Laboratory.

[2] All glues listed are of the thermosetting type unless otberwise stated in this column.

[3] Glues suggested for bag-molding by the manufacturers.

[4] Recommended for bonding bigh density, compregnated, and heat-stabilized wood, as well as normal wood.

[5] Designed primarily for Douglas-fir and similar woods.

[6] Not recommended for use with fluid pressure.

[7] Not recommended for use with rigid pressure.

4.21. Phenol-formaldehyde Type Glues. The phenol-formaldehyde glues may be classified or grouped on a number of characteristics such as hot-press and low-temperature types, film, powder and liquid forms, and kind of solvent.

The film form of phenolic glue requires no preparation for use, and a single sheet is usually laid between the surfaces to be joined. Since the film does not add moisture to the wood, it is particularly well adapted to the gluing of thin veneers, such as $\frac{1}{100}$ to $\frac{1}{32}$ inch. When a film glue is used, the moisture content of the stock must be closely controlled, usually between 8 and 12 percent. To obtain good joints with the film glue, the surface of the veneer should be smooth because the amount of glue applied cannot be increased to accommodate rough or poorly cut stock. For the film form, the assembly period (the time between applying the glue and pressing) is not critical and may vary over a wide range.

The liquid forms of phenolic-resin glues, either water suspensions or nonaqueous solutions, can be advantageously applied to veneers by means of mechanical spreaders with rubber-covered rolls in much the same way as casein glues are applied with grooved steel rolls. With the liquid-resin glues, the quantity of spread can be varied to suit operating requirements better than it can with the film type, and they are, therefore, preferred for some operations. The control of moisture in the wood is somewhat less exacting with the liquid forms of phenolic-resin glues than with the film forms, but some trouble with steam blisters may be expected in making hot-press plywood at high temperatures if the total moisture present in the assembly at the time of pressing is too high. Ordinarily, a moisture content of about 12 percent at the time of pressing is the maximum, above which a decided increase in blistering may be expected. For most hot-press, phenolic-resin glues, the coated veneers are allowed to dry under atmospheric or slightly elevated temperatures until in approximate equilibrium. The pressing may then be done immediately or delayed for several days. The platen temperatures for gluing with hot-press phenolic-resin glues of both the film and liquid forms are normally from 280° to 310° F.

4.22. Low-temperature Phenolic-type Glues. Several phenolic and resorcinol resins and combinations of them have recently been developed, which set at temperatures substantially lower than those necessary for hot-press phenols. Some of them cure at temperatures of 150° to 200° F. and present indications are that glues of this type are, or soon will be, available that set at still lower temperatures. Because these glues cure at lower temperatures, the assembly period cannot be as long as that allowed for high-temperature glues.

4.23. Melamine-formaldehyde Glues. Melamine glues are available in hot-press and low-temperature types, in film and powder forms, and as water- and alcohol-soluble materials. In general, their use characteristics are similar to those of the phenol-formaldehyde glues of the same type and form, except that temperatures required for curing the hot-press melamines are usually somewhat lower than for hot-press phenols.

4.24. Urea-resin Glues. Urea-resin glues are marketed either as dry powders or as water suspensions ordinarily containing 60 to 70 percent of solids. Most of those marketed as liquids may be used as received or after the addition of small amounts of catalyst, which increases the rate of setting. The dry-powder types are mixed with water to produce suspensions having concentrations approximately the same as those marketed as liquids.

In general, urea-resin glues in powder form have a longer storage life than those in liquid form. Some urea-resin glues are formulated for use at room temperatures and others for hot-pressing operations.

Urea-resin glues are most advantageously applied to wood by mechanical spreaders with rubber-covered rolls, although the consistency of the glue is such that it can be spread with a brush if desired

Urea-resin glues are not particularly critical with respect to the moisture content of the wood at the time of gluing. The most desirable moisture content will ordinarily be governed by considerations other than its effect on the quality of the joint. When hot pressing with urea-resin glues at high temperatures, the same limitations on moisture contents must be observed, in order to avoid blistering, as with phenolic-resin glues. In hot pressing with high temperature setting urea-resin glues, the assembly periods are ordinarily not critical and may be varied over comparatively wide limits—some of them, for example, for more than 24 hours. Urea-resin glues formulated for hot pressing set at temperatures somewhat below those required for phenolic-resin glues.

Cold-setting, urea-resin glues are prepared and applied to wood in the same way as the hot-press, urea resins. The rate of setting of the cold urea resins at room temperatures is much slower, of course, than that in hot presses. The working life of the urea-resin mixtures and their rate of setting in the joints are dependent on the temperature of both the gluing room and the wood. In hot weather, it may be desirable to surround the glue container with a water bath in which cool water is circulated to maintain the temperature of the glue mixture at from 70° to 75° F.

Joints made with cold-setting, urea-resin glues must be allowed to remain under pressure longer if the temperature is 70° F., for example, than if the gluing room and wood are at 90° F. The use of the cold-setting, urea-resin glues is prohibited by Specification AN-G-20 when the temperature of the wood or the gluing room is below 70° F.

The assembly periods for cold-setting, urea resins are more limited than are those for hot-press, urea resins.

4.25. "Fortified" Urea-resin Glues. Other urea-resin glues have been developed for special purposes. Some of these glues, for example, have been developed primarily to improve the resistance of urea-resin glue joints to boiling water. Other formulas have been developed primarily for the gluing of curved plywood by the bag-molding technique, and these glues are characterized by the property of permitting very long assembly periods, although some will set quickly at temperatures at or near 212° F. Such glues are sometimes marketed under the term "fortified urea-resin glues," the implication being that the resistance has been increased in some particular over that ordinarily associated with urea-resin glues. Other glues that may be classified under the term "fortified urea-resin glues" are marketed under names indicating their basic composition, of which the melamine-urea-resin glue is one example.

4.26. Casein Glues. The use characteristics of casein glues have been reported in several publications (*4–7*, *4–6*, *4–8*) and are quite generally known to woodworkers. Their use over many years has generally resulted in good shop practices. In working life, assembly time, pressure, and rate of setting, at ordinary room temperature they are similar to cold-setting, urea resins and in general are subject to the same limitations and adapted to the same gluing operations. They do, however, set at temperatures lower than those at which the cold-setting, urea resins can be used. The addition of preservatives to casein glues may affect somewhat the consistency or viscosity of the glue mixture and the working life but, in general, the use characteristics of casein glues containing preservatives are similar to those of casein glues without preservatives.

4.3. CONTROL OF GLUE QUALITY.

4.30. General. Glues for use in aircraft should be systematically tested to insure that they conform to standard specifications and requirements before they are put in production. Thereafter, they should be checked sufficiently often to make certain that they have not deteriorated during storage or for some other reason do not come up to current requirements.

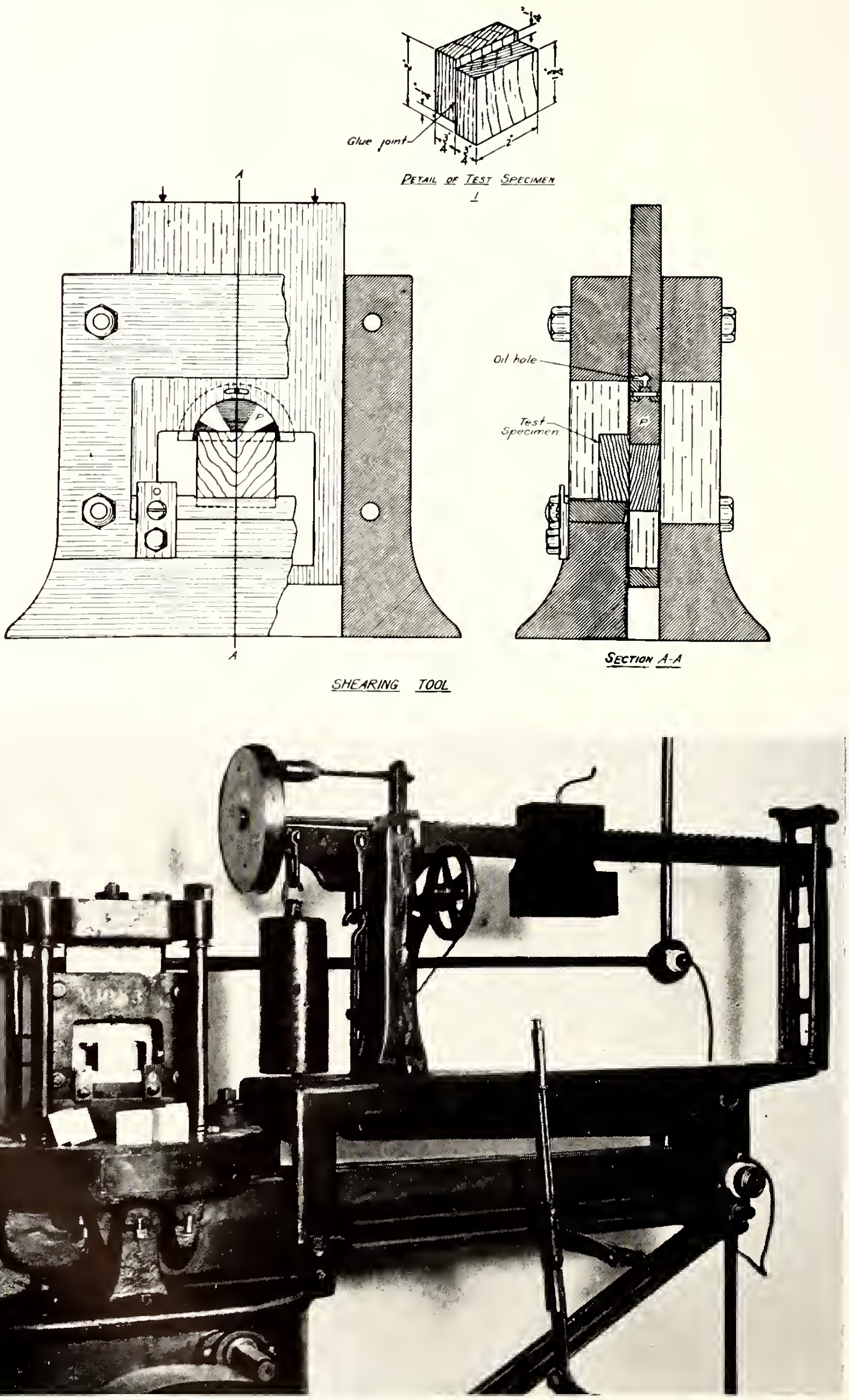

FIGURE 4-7.—Block shear joint test: (*Above*) Test specimen and shear tool; (*below*) testing machine.

The testing of casein and cold-setting resin glues and the requirements for their use in aircraft are covered by specifications as follows:

Water-resistant casein glue: Federal Specification CG–456, July 8, 1941, and Navy Specification No. 52G8c, July 1, 1932.

Glue; water- and mold-resistant casein: Army Air Forces Specification No. 14122.

Cold-setting resin glue: Army-Navy Aeronautical Specification No. AN–G–8, April 25, 1942.

4.31. Joint Tests. It is not practical for the fabricator of aircraft to test the glue used by the plywood manufacturer in the production of plywood. The quality and kind of glue used in the production of the plywood can, however, be controlled within safe limits by tests on the finished plywood. The requirements for flat plywood for use in the fabrication of structural or highly stressed parts of aircraft are covered by Army-Navy Aeronautical Specification No. AN–NN–P–511b, March 19, 1943, and for molded plywood by Army-Navy Aeronautical Specification No. AN–P–43, March 30, 1943. These specifications limit the glues used to hot-press, thermosetting, synthetic-resin types.

The requirements for aircraft plywood and for casein and cold-setting resin glues in the foregoing specifications are based in part on results obtained in joint tests. Information on preparing the test material and making the tests is given in the published literature (*4–8*, *4–9*) and is ample and readily available. Inasmuch as the block shear and plywood joint tests are currently used in Army-Navy Aeronautical specifications, and since most of the test data herein presented on glue properties and use are based on these tests, specimens and testing equipment are shown in figures 4–7 and 4–8, and the more important points of procedure are summarized below:

4.32. Block Shear Joint Test.

1. Use a wood of high density (hard maple of not less than 0.65 specific gravity is considered standard), of straight grain, and free from defects. Condition to a moisture content of about 7 percent.
2. Cut the material into pieces about 1 by 2.5 by 12 inches, or of such other width and length as to provide at least four specimens of the dimensions shown in figure 4–7. Surface the pieces smoothly to a uniform thickness and glue promptly after surfacing.
3. Glue at least two joints for each test.
4. Follow the manufacturer's directions carefully in mixing the glue. Weigh the component parts.
5. Spread the glue evenly on one of the two pieces and apply pressure uniformly to the joint within the assembly period limitations of the specification. The quantity of the glue spread can be determined by weighing the pieces immediately before and after spreading.
6. Apply a pressure of 150 to 200 pounds per square inch and leave the test blocks under pressure not less than 4 hours and condition them for 6 additional days at room temperature before testing.
7. Cut the glued blocks into specimens of the form and dimensions shown in figure 4–7 and test on a universal testing machine equipped with a shearing tool illustrated in figure 4–7. Apply the load to the specimens at 0.015 inch per minute, plus or minus 25 percent.
8. Record for each specimen tested the breaking load and the approximate percentage of wood failure occurring over the glue-line area. Compute the breaking load in terms of pounds per square inch of glue-line area.

4.33. Plywood Joint Test.

1. Glue 3-ply panels with the grain of the face plies at right angles to that of the core. The veneer should be selected for firmness, straightness of grain, and freedom from defects ($\frac{1}{16}$-inch yellow birch is considered standard).

2. Each panel should be of a size sufficient to produce at least 10 specimens of the form and dimensions shown in figure 4–8. A panel measuring 4 inches with the grain and 12 inches across the grain of the faces is a convenient size for cutting the required number of specimens.

3. Condition the veneer to a moisture content of about 7 percent.

4. Follow the manufacturer's directions carefully in mixing the glue.

5. Glue the plywood under carefully controlled conditions.

6. Condition the panels after gluing in accordance with provisions of current specifications.

7. From each panel cut 10 specimens of the form and dimensions shown as specimen A or B in figure 4–8. Specimen A is used when face plies are thicker than 0.047 inch and specimen B when face plies are 0.047 inch or less in thickness. Number the specimens from each panel successively from 1 to 10.

8. Test in the dry condition the odd-numbered specimens from each panel in a cement briquette testing machine equipped with special grips as shown in figure 4–8. Apply the load to the specimens at a rate between 600 and 1,000 pounds per minute.

9. For wet tests, soak or otherwise expose the even-numbered specimens to moisture as specified, and while still wet test in the same manner as described in paragraph 8 above.

10. Record for each specimen tested the breaking load and the approximate percentage of wood failure occurring in the test.

4.34. Glue References.

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(4–9) ———, Browne, F. L., and Brouse, D.
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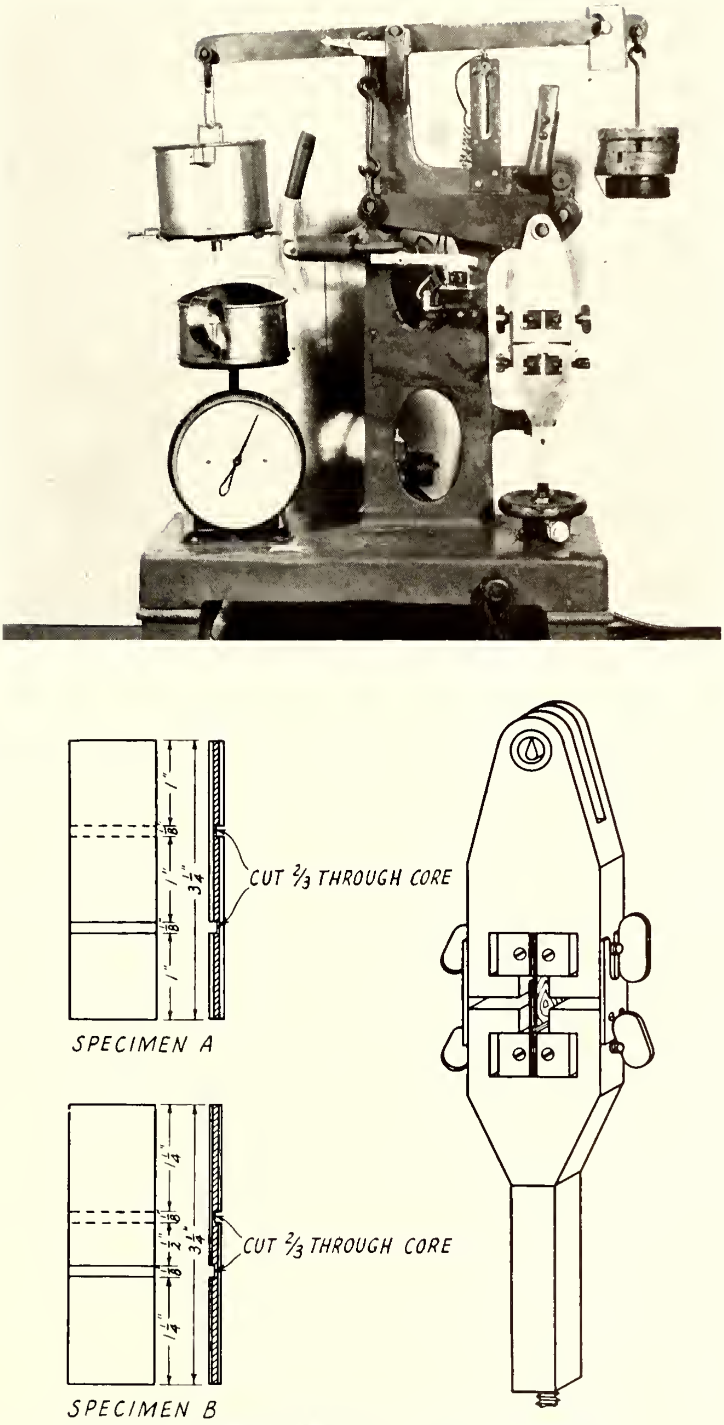

FIGURE 4-8.—Plywood joint test: (*Right*) Test specimens and grips; (*left*) testing machine.

CHAPTER 5. PROCESSING AND FABRICATION

5.0. SEASONING AND STORAGE OF LUMBER.

5.01. General. The quantity of water in wood cut from a living tree may have a weight that is one-third to three times the oven-dry weight of the wood; a freshly cut log 16 feet long and 18 inches in diameter may have a liquid content of more than 100 gallons.

Sap, which is principally water, is the lifeblood of a living tree; but after the tree is felled and converted into lumber most of this moisture must be removed before the material is suitable for use. The moisture present in wood has an influence upon its strength and resistance to decay. Changes in moisture content cause changes in dimension (sec. 2.240). In the seasoning process, considerable shrinkage takes place, and precautions must be taken to prevent the unequal shrinkage stresses from causing defects, such as warping, checking, splitting, and case-hardening. The proper moisture content at the time of manufacture is that which is best suited for the conditions to which the material will be subjected during manufacture and, later, during use. Specifications for airplane parts define limits that are intended to cover this range, so that subsequent changes in moisture content will not be large enough to cause troublesome swelling and shrinkage. The final average moisture content allowed for propeller stock is lower than for other airplane parts. Propeller stock must be uniform in moisture content, both as to moisture distribution within each piece and as between the various pieces which make up the propeller. This condition is most likely to be attained when stock is dried to the moisture content specified.

Details of how to determine the moisture content in wood are given in section 2.21.

5.010. The Moisture Content of Wood is Dependent Upon the Humidity and Temperature of the Surrounding Air. When wood is subjected to a constant temperature and relative humidity it will in time come to a definite moisture content, which is called the equilibrium moisture content (*5–1*). This relationship between the moisture content of wood and the surrounding atmospheric conditions is shown in figure 5–1 for Sitka spruce, but is generally applicable to other species. Note that under constant temperature conditions the moisture content increases as the relative humidity increases, and that under constant relative humidity conditions the moisture content decreases as the temperature increases. In general, relative humidities are lower in the spring and summer than during the autumn and winter, and seasoned wood exposed to these changes in humidity will absorb or lose moisture accordingly.

5.011. Geographical Variations in Relative Humidity. In addition to variations due to season, there is also a variation in relative humidity in different parts of the country as affected by altitude, proximity to the ocean, precipitation, or some comparatively local condition. Table 5–1 shows the relative humidity for a number of widely separated cities in the United States at different times of the year. Similar seasonal variations occur in other parts of the world. In tropical and subtropical areas, where long rainy seasons are followed by long dry spells, the spread of equilibrium moisture content between seasons may be considerable. Low equilibrium moisture content conditions may be expected in desert areas, while in Europe

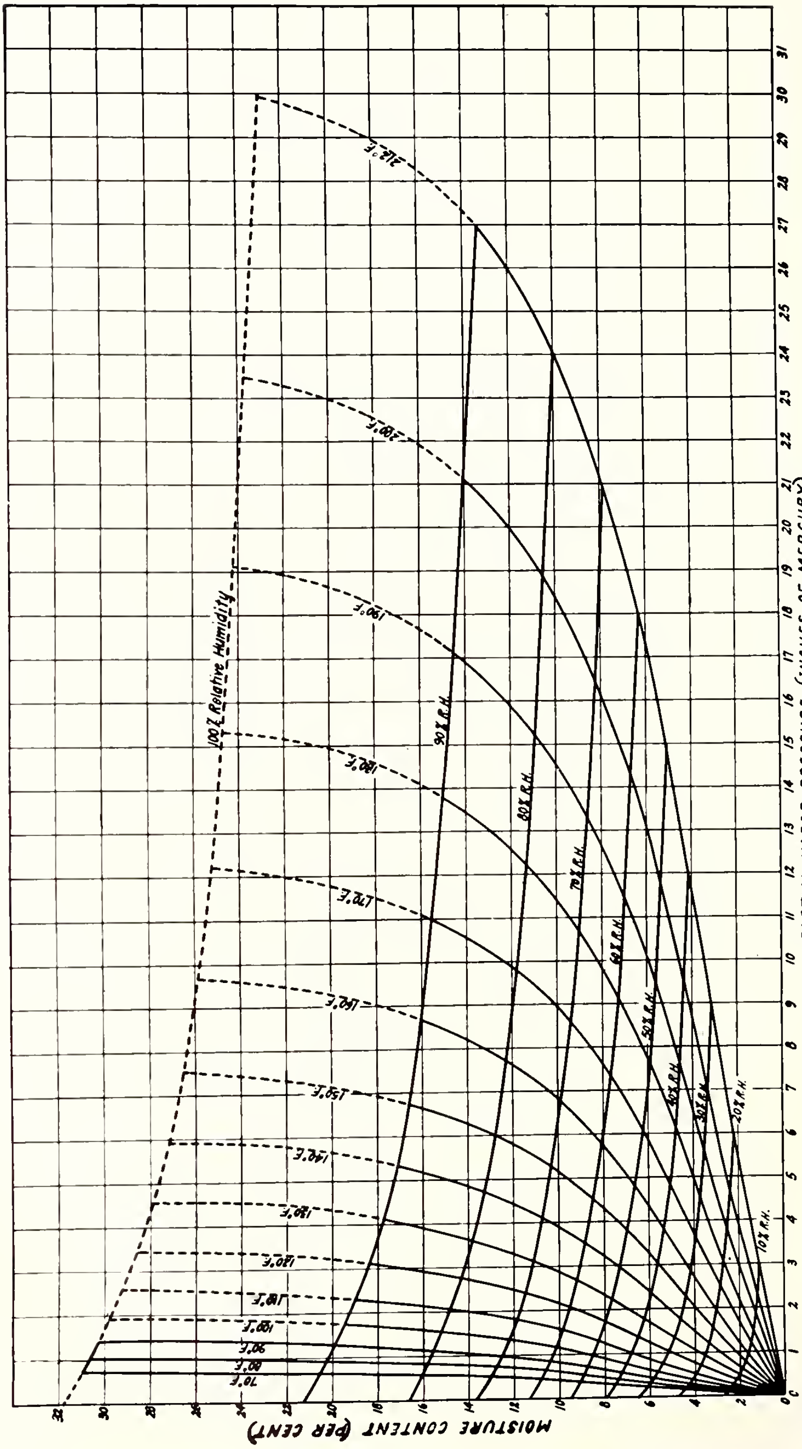

FIGURE 5-1.—The moisture content of Sitka spruce at equilibrium with the indicated temperature, partial vapor pressure, and relative humidity.

generally the average equilibrium moisture content would be as high as, or higher than, that along the northeastern coast of the United States.

The approximate equilibrium moisture content for wood can be estimated for any section of the country and for any season by noting the relative humidity given in table 5–1 and reading the corresponding moisture content from figure 5–1 at the particular temperature under consideration. In this figure the solid curved lines marked "RH" denote relative humidity, and the intersecting solid and dashed lines denote temperature.

TABLE 5–1.—*Relative humidities at different seasons in various parts of the United States* [1]

City	Mean relative humidity in percent, based on daytime readings			
	Winter	Spring	Summer	Autumn
New York, N. Y	73	70	74	75
Cleveland, Ohio	77	72	70	74
Spokane, Wash	82	61	47	67
Seattle, Wash	83	73	69	81
Phoenix, Ariz	47	32	32	41
San Diego, Calif	74	78	81	78
San Francisco, Calif	79	79	84	80
Denver, Colo	54	51	49	46
Washington, D. C	72	69	75	76
El Paso, Tex	45	27	41	46
Galveston, Tex	84	82	79	78
Jacksonville, Fla	80	74	80	83

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[1] The relative humidities given here are based on daytime readings made by the U. S. Weather Bureau and do not give the mean average humidity for 24-hour periods. The relative humidity during the night is usually much higher than during the day, and the equilibrium moisture content will follow the mean average humidity for the 24-hour period.

5.012. Determination of Atmospheric Humidity. The amount of water vapor in the air, which is termed "humidity," is usually expressed either in grains per cubic foot or as a percentage of saturation; the first method of expression is called absolute humidity, and the second is called relative humidity. Fortunately, the amount of water vapor that a given amount of air can hold at a given temperature is a fixed quantity; when this quantity is present the air is said to be saturated. The amount of water vapor at the saturation point of air increases rapidly with increase in temperature. At 60° F., 5.8 grains of water vapor per cubic foot saturate the ordinary atmosphere, whereas at 212° F. it will hold about 260 grains per cubic foot. It is generally more convenient to consider the amount of water vapor in the air in terms of relative humidity than as absolute humidity. As already intimated, relative humidity is always expressed as a percentage of saturation.

The lower relative humidities represent dry air, and the higher ones, moist air. Air at a temperature of 125° F., for instance, can hold a maximum of 40 grains of water vapor per cubic foot. If a certain atmosphere at that temperature had only 10 grains of water per cubic foot, it would have only 10/40 of the maximum amount it could hold, which is a relative humidity of 25 percent. Air with 25 percent relative humidity is comparatively dry. At 125° F., the relative humidity of air having 30 grains of water vapor would be 30/40, or 75 percent; such air would be considered moist. The preceding example may be expressed by the following formula:

$$\text{Relative humidity percent} = \frac{\text{amount of water vapor actually present in a given space}}{\begin{array}{c}\text{maximum amount of water vapor possible (the saturation}\\ \text{value) in the same space under the same temperature}\end{array}} \times 100$$

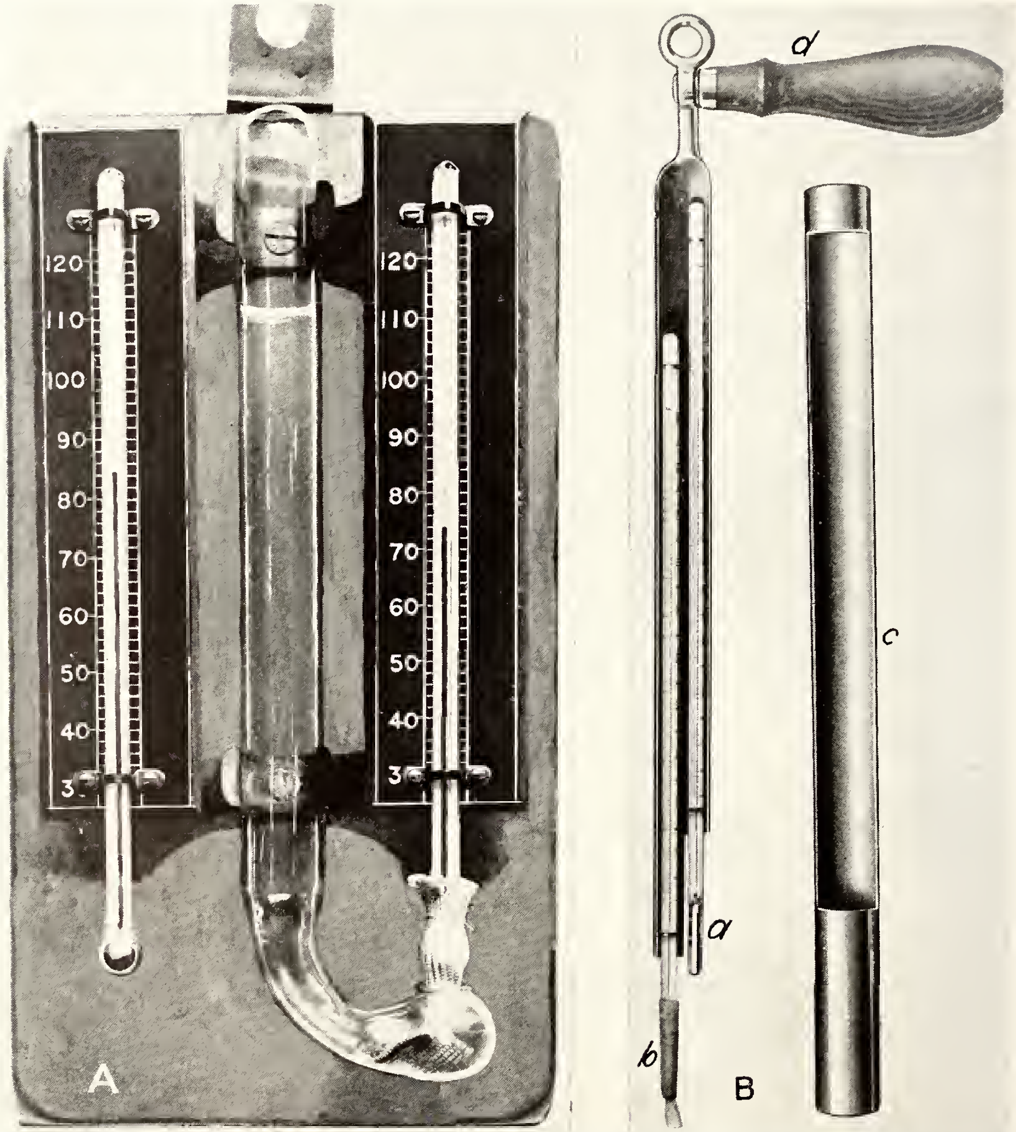

FIGURE 5-2.—*A*, Wet- and dry-bulb hygrometer. The central reservoir must be filled with water to keep the wick always moist. Accurate readings require brisk circulation of air past the wet bulb; this is usually secured by fanning. *B*, Sling psychrometer. The air circulation needed to procure evaporation from the wet wick *b* is secured by whirling the instrument around the handle *d*; the sleeve *c* protects both the dry bulb *a* and the wet bulb.

At any given temperature dry air is heavier than moist air. Hot air always is lighter than cold air at the same relative humidity and the same pressure. When water is evaporated from wood, the heat required for evaporation is absorbed from the air that carries away the water vapor, with resultant cooling of the air; the net effect, in consequence, is to make the air heavier, since the gain in weight brought about by the cooling outweighs the weight loss caused by the increase in humidity.

The humidity of the surrounding air not only determines largely the rate at which materials will dry, but it also determines the extent to which they can be dried. The relation between humidity in the air and moisture in the wood is an important one, since it is closely related to all drying schedules and, further, determines the extent to which wood for use under specified conditions of temperature and humidity should be dried. Since humidity determines the drying characteristics of air at any given temperature, the control of humidity in the kiln is of prime importance. It is essential that the moisture be removed from the wood surface at the maximum safe drying rate. If the humidity is too low, the wood will dry too fast and will be injured; if the humidity is too high, the drying will be slow and expensive.

Relative humidity may be measured in a number of different ways, but the wet- and dry-bulb thermometer is almost universally used for such measurement in dry kilns (fig. 5–2). This instrument is also known as a hygrometer and as a psychrometer. The silk or muslin wick for one of the two thermometers of the instrument, kept moist by the reservoir of water into which it dips, is cooled a certain amount by the evaporation of water from its surface when it is exposed to a breeze of nonsaturated air, and in turn it cools the wet bulb it encloses, thus causing the wet-bulb temperature indication to drop. The amount of cooling is constant for any given temperature and humidity, provided that the reservoir contains water enough to keep the wick moist and that the velocity of the cooling air is sufficient. If the amount of the cooling, called wet-bulb depression, and the temperature of the air are known, the relative humidity can be determined by formula or by reference to a chart or table such as table 5–2. In practice, the reading of the dry-bulb thermometer gives the air temperature, and the difference between that reading and the reading of the separate wet-bulb thermometer gives the wet-bulb depression; both thermometers are mounted on one panel.

To assure accuracy, it is essential that the wick be clean and that there be a brisk circulation of air over the wet bulb. A velocity of at least 15 feet per second is desirable for accurate readings at atmospheric temperatures. At ordinary kiln temperatures, however, sufficient accuracy can be secured with very much lower air velocities.

With certain types of wet-and dry-bulb thermometers, circulation past the wet bulb is produced by whirling the entire instrument. Such instruments are know as sling psychrometers (fig. 5–2, B). Other instruments are provided with maximum-reading thermometers, so that they can be removed from the kiln and read outside. The mercury or other fluid column in these thermometers must be shaken down before they are used again. They indicate only the maximum wet- and dry-bulb temperatures since they were last shaken down. If the temperature and humidity variations have been reasonably great during this time, the readings will be misleading.

Table 5–2 is for use with wet- and dry-bulb thermometers. It is based on the difference between the wet- and dry-bulb temperature. The dry-bulb temperatures are in the left-hand column and the differences between wet- and dry-bulb temperatures are in the top row. Both relative humidity and equilibrium moisture content values are given at the intersection of the row and the column. Suppose the dry bulb reads 140° F., and the wet bulb 130° F.; the difference between them is 10°. By reading across the 140 row to column 10, the relative humidity of the air will be found to be 75 percent and the equilibrium moisture content of wood 12 percent.

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TABLE 5-2.—*Relative humidity*[1] *and equilibrium moisture content*[2] *table for use with dry-bulb temperatures and wet-bulb depressions*

Temperature dry bulb (°F.)	Wet bulb—depression (°F.)																																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	32	34	36	38	40	45	50
30	89	78	67	57	46	36	27	17	6	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	---	*15.9*	*12.9*	*10.8*	*9.0*	*7.4*	*5.7*	*3.9*	*1.6*	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
35	90	81	72	63	54	45	37	28	19	11	3	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	---	*16.8*	*13.9*	*11.9*	*10.3*	*8.8*	*7.4*	*6.0*	*4.5*	*2.9*	*0.8*	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
40	92	83	75	68	60	52	45	37	29	22	15	8	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	---	*17.6*	*14.8*	*12.9*	*11.2*	*9.9*	*8.6*	*7.4*	*6.2*	*5.0*	*3.5*	*1.9*	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
45	93	85	78	72	64	58	51	44	37	31	25	19	12	6	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	---	*18.3*	*15.6*	*13.7*	*12.0*	*10.7*	*9.5*	*8.5*	*7.5*	*6.5*	*5.3*	*4.2*	*2.9*	*1.5*	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
50	93	86	80	74	68	62	56	50	44	38	32	27	21	16	10	5	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	---	*19.0*	*16.3*	*14.4*	*12.7*	*11.5*	*10.3*	*9.4*	*8.5*	*7.6*	*6.7*	*5.7*	*4.8*	*3.9*	*2.8*	*1.5*	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
55	94	88	82	76	70	65	60	54	49	44	39	34	28	24	19	14	9	5	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	---	*19.5*	*16.9*	*15.1*	*13.4*	*12.2*	*11.0*	*10.1*	*9.3*	*8.4*	*7.6*	*6.8*	*6.0*	*5.3*	*4.5*	*3.6*	*2.5*	*1.3*	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
60	94	89	83	78	73	68	63	58	53	48	43	39	34	30	26	21	17	13	9	5	1	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	---	*19.9*	*17.4*	*15.6*	*13.9*	*12.7*	*11.6*	*10.7*	*9.9*	*9.1*	*8.3*	*7.6*	*6.9*	*6.3*	*5.6*	*4.9*	*4.1*	*3.2*	*2.3*	*1.3*	*0.2*	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
65	95	90	84	80	75	70	66	61	56	52	48	44	39	36	32	27	24	20	16	13	8	6	2	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	---	*20.3*	*17.8*	*16.1*	*14.4*	*13.3*	*12.1*	*11.2*	*10.4*	*9.7*	*8.9*	*8.3*	*7.7*	*7.1*	*6.5*	*5.8*	*5.2*	*4.5*	*3.8*	*3.0*	*2.3*	*1.4*	*0.4*	---	---	---	---	---	---	---	---	---	---	---	---	---	---
70	95	90	86	81	77	72	68	64	59	55	51	48	44	40	36	33	29	25	22	19	15	12	9	6	3	---	---	---	---	---	---	---	---	---	---	---	---
	---	*20.6*	*18.2*	*16.5*	*14.9*	*13.7*	*12.5*	*11.6*	*10.9*	*10.1*	*9.4*	*8.8*	*8.3*	*7.7*	*7.2*	*6.6*	*6.0*	*5.5*	*4.9*	*4.3*	*3.7*	*2.9*	*2.3*	*1.5*	*0.7*	---	---	---	---	---	---	---	---	---	---	---	---
75	95	91	86	82	78	74	70	66	62	58	54	51	47	44	41	37	34	31	28	24	21	18	15	12	10	7	4	1	---	---	---	---	---	---	---	---	---
	---	*20.9*	*18.5*	*16.8*	*15.2*	*14.0*	*12.9*	*12.0*	*11.2*	*10.5*	*9.8*	*9.3*	*8.7*	*8.2*	*7.7*	*7.2*	*6.7*	*6.2*	*5.6*	*5.1*	*4.7*	*4.1*	*3.5*	*2.9*	*2.3*	*1.7*	*0.9*	*0.2*	---	---	---	---	---	---	---	---	---
80	96	91	87	83	79	75	72	68	64	61	57	54	50	47	44	41	38	35	32	29	26	23	20	18	15	12	10	7	5	3	---	---	---	---	---	---	---
	---	*21.0*	*18.7*	*17.0*	*15.5*	*14.3*	*13.2*	*12.3*	*11.5*	*10.9*	*10.1*	*9.7*	*9.1*	*8.6*	*8.1*	*7.7*	*7.2*	*6.8*	*6.3*	*5.8*	*5.4*	*5.0*	*4.5*	*4.0*	*3.5*	*3.0*	*2.4*	*1.8*	*1.1*	*0.3*	---	---	---	---	---	---	---
85	96	92	88	84	80	76	73	70	66	63	59	56	53	50	47	44	41	38	36	33	30	28	25	23	20	18	15	13	11	9	4	---	---	---	---	---	---
	---	*21.2*	*18.8*	*17.2*	*15.7*	*14.5*	*13.5*	*12.5*	*11.8*	*11.2*	*10.5*	*10.0*	*9.5*	*9.0*	*8.5*	*8.1*	*7.6*	*7.2*	*6.7*	*6.3*	*6.0*	*5.6*	*5.2*	*4.8*	*4.3*	*3.9*	*3.4*	*3.0*	*2.4*	*1.7*	*0.9*	---	---	---	---	---	---
90	96	92	89	85	81	78	74	71	68	65	61	58	55	52	49	47	44	41	39	36	34	31	29	26	24	22	19	17	15	13	9	5	1	---	---	---	---
	---	*21.3*	*18.9*	*17.3*	*15.9*	*14.7*	*13.7*	*12.8*	*12.0*	*11.4*	*10.7*	*10.2*	*9.7*	*9.3*	*8.8*	*8.4*	*8.0*	*7.6*	*7.2*	*6.8*	*6.5*	*6.1*	*5.7*	*5.3*	*4.9*	*4.6*	*4.2*	*3.8*	*3.3*	*2.8*	*2.1*	*1.3*	*0.4*	---	---	---	---
95	96	92	89	85	82	79	75	72	69	66	63	60	57	55	52	49	46	44	42	39	37	34	32	30	28	26	23	22	20	17	14	10	6	2	---	---	---
	---	*21.3*	*19.0*	*17.4*	*16.1*	*14.9*	*13.9*	*12.9*	*12.2*	*11.6*	*11.0*	*10.5*	*10.0*	*9.5*	*9.1*	*8.7*	*8.2*	*7.9*	*7.5*	*7.1*	*6.8*	*6.4*	*6.1*	*5.7*	*5.3*	*5.1*	*4.8*	*4.4*	*4.0*	*3.6*	*3.0*	*2.3*	*1.5*	*0.6*	---	---	---
100	96	93	89	86	83	80	77	73	70	68	65	62	59	56	54	51	49	46	44	41	39	37	35	33	30	28	26	24	22	21	17	13	10	7	4	---	---
	---	*21.3*	*19.0*	*17.5*	*16.1*	*15.0*	*13.9*	*13.1*	*12.4*	*11.8*	*11.2*	*10.6*	*10.1*	*9.6*	*9.2*	*8.9*	*8.5*	*8.1*	*7.8*	*7.4*	*7.0*	*6.7*	*6.4*	*6.1*	*5.7*	*5.4*	*5.2*	*4.9*	*4.6*	*4.2*	*3.6*	*3.1*	*2.4*	*1.6*	*0.7*	---	---
105	96	93	90	87	83	80	77	74	71	69	66	63	60	58	55	53	50	48	46	44	42	40	37	35	34	31	29	28	26	24	20	17	14	11	8	---	---
	---	*21.4*	*19.0*	*17.5*	*16.2*	*15.1*	*14.0*	*13.2*	*12.6*	*11.9*	*11.3*	*10.8*	*10.3*	*9.8*	*9.4*	*9.0*	*8.7*	*8.3*	*7.9*	*7.6*	*7.3*	*6.9*	*6.7*	*6.4*	*6.1*	*5.7*	*5.4*	*5.2*	*4.8*	*4.6*	*4.2*	*3.6*	*3.1*	*2.4*	*1.8*	---	---
110	97	93	90	87	84	81	78	75	73	70	67	65	62	60	57	55	52	50	48	46	44	42	40	38	36	34	32	30	28	26	23	20	17	14	11	4	---
	---	*21.4*	*19.0*	*17.5*	*16.2*	*15.1*	*14.1*	*13.3*	*12.6*	*12.0*	*11.4*	*10.8*	*10.4*	*9.9*	*9.5*	*9.2*	*8.8*	*8.4*	*8.1*	*7.7*	*7.5*	*7.2*	*6.8*	*6.6*	*6.3*	*6.0*	*5.7*	*5.4*	*5.2*	*4.8*	*4.5*	*4.0*	*3.5*	*3.0*	*2.5*	*1.1*	---
115	97	93	90	88	85	82	79	76	74	71	68	66	63	61	58	56	54	52	50	48	45	43	41	40	38	36	34	32	31	29	26	23	20	17	14	8	2
	---	*21.4*	*19.0*	*17.5*	*16.2*	*15.1*	*14.1*	*13.4*	*12.7*	*12.1*	*11.5*	*10.9*	*10.4*	*10.0*	*9.6*	*9.3*	*8.9*	*8.6*	*8.2*	*7.8*	*7.6*	*7.3*	*7.0*	*6.7*	*6.5*	*6.2*	*5.9*	*5.6*	*5.4*	*5.2*	*4.7*	*4.3*	*3.9*	*3.4*	*2.9*	*1.7*	*0.4*
120	97	94	91	88	85	82	80	77	74	72	69	67	65	62	60	58	55	53	51	49	47	45	43	41	40	38	36	34	33	31	28	25	22	19	17	10	5
	---	*21.3*	*19.0*	*17.4*	*16.2*	*15.1*	*14.1*	*13.4*	*12.7*	*12.1*	*11.5*	*11.0*	*10.5*	*10.0*	*9.7*	*9.4*	*9.0*	*8.7*	*8.3*	*7.9*	*7.7*	*7.4*	*7.2*	*6.8*	*6.6*	*6.3*	*6.1*	*5.8*	*5.6*	*5.4*	*5.0*	*4.6*	*4.2*	*3.7*	*3.3*	*2.3*	*1.1*
125	97	94	91	88	86	83	80	77	75	73	70	68	65	63	61	59	57	55	53	51	48	47	45	43	41	39	38	36	35	33	30	27	24	22	19	13	8
	---	*21.2*	*18.9*	*17.3*	*16.1*	*15.0*	*14.0*	*13.4*	*12.7*	*12.1*	*11.5*	*11.0*	*10.5*	*10.0*	*9.7*	*9.4*	*9.0*	*8.7*	*8.3*	*8.0*	*7.7*	*7.5*	*7.2*	*7.0*	*6.7*	*6.5*	*6.2*	*6.0*	*5.8*	*5.5*	*5.2*	*4.8*	*4.4*	*4.0*	*3.6*	*2.7*	*1.6*
130	97	94	91	89	86	83	81	78	76	73	71	69	67	64	62	60	58	56	54	52	50	48	47	45	43	41	40	38	37	35	32	29	26	24	21	15	10
	---	*21.0*	*18.8*	*17.2*	*16.0*	*14.9*	*14.0*	*13.4*	*12.7*	*12.1*	*11.5*	*11.0*	*10.5*	*10.0*	*9.7*	*9.4*	*9.0*	*8.7*	*8.3*	*8.0*	*7.8*	*7.6*	*7.3*	*7.0*	*6.8*	*6.6*	*6.4*	*6.1*	*5.9*	*5.6*	*5.3*	*4.9*	*4.6*	*4.2*	*3.8*	*3.0*	*2.0*
140	97	95	92	89	87	84	82	79	77	75	73	70	68	66	64	62	60	58	56	54	53	51	49	47	46	44	43	41	40	38	35	32	30	27	25	19	14
	---	*20.7*	*18.6*	*16.9*	*15.8*	*14.8*	*13.8*	*13.2*	*12.5*	*11.9*	*11.4*	*10.9*	*10.4*	*10.0*	*9.6*	*9.4*	*9.0*	*8.7*	*8.4*	*8.0*	*7.8*	*7.6*	*7.3*	*7.1*	*6.9*	*6.6*	*6.4*	*6.2*	*6.0*	*5.8*	*5.4*	*5.1*	*4.8*	*4.4*	*4.1*	*3.4*	*2.6*
150	98	95	92	90	87	85	82	80	78	76	74	72	70	68	66	64	62	60	58	57	55	53	51	49	48	46	45	43	42	41	38	36	33	30	28	23	18
	---	*20.2*	*18.4*	*16.6*	*15.4*	*14.5*	*13.7*	*13.0*	*12.4*	*11.8*	*11.2*	*10.8*	*10.3*	*9.9*	*9.5*	*9.2*	*8.9*	*8.6*	*8.3*	*8.0*	*7.8*	*7.5*	*7.3*	*7.1*	*6.9*	*6.7*	*6.4*	*6.2*	*6.0*	*5.8*	*5.4*	*5.2*	*4.9*	*4.5*	*4.2*	*3.6*	*2.9*
160	98	95	93	90	88	86	83	81	79	77	75	73	71	69	67	65	64	62	60	58	57	55	53	52	50	49	47	46	44	43	41	38	35	33	31	25	21
	---	*19.8*	*18.1*	*16.2*	*15.2*	*14.2*	*13.4*	*12.7*	*12.1*	*11.5*	*11.0*	*10.6*	*10.1*	*9.7*	*9.4*	*9.1*	*8.8*	*8.5*	*8.2*	*7.9*	*7.7*	*7.4*	*7.2*	*7.0*	*6.8*	*6.7*	*6.4*	*6.2*	*6.0*	*5.8*	*5.5*	*5.2*	*4.9*	*4.6*	*4.3*	*3.7*	*3.2*
170	98	95	93	91	89	86	84	82	80	78	76	74	72	70	69	67	65	63	62	60	59	57	55	53	52	51	49	48	47	45	43	40	38	35	33	28	24
	---	*19.4*	*17.7*	*15.8*	*14.8*	*13.9*	*13.2*	*12.4*	*11.8*	*11.3*	*10.8*	*10.4*	*9.9*	*9.6*	*9.2*	*9.0*	*8.6*	*8.4*	*8.0*	*7.8*	*7.6*	*7.3*	*7.2*	*6.9*	*6.7*	*6.6*	*6.4*	*6.2*	*6.0*	*5.7*	*5.5*	*5.2*	*4.9*	*4.6*	*4.4*	*3.7*	*3.2*

180	98	96	94	91	89	87	85	83	81	79	77	75	73	72	70	68	67	65	63	62	60	58	57	55	54	52	51	50	48	47	45	42	40	38	35	30	26
	---	*18.9*	*17.3*	*15.5*	*14.5*	*13.7*	*12.9*	*12.2*	*11.6*	*11.1*	*10.6*	*10.1*	*9.7*	*9.4*	*9.0*	*8.8*	*8.4*	*8.1*	*7.8*	*7.6*	*7.4*	*7.2*	*7.0*	*6.8*	*6.5*	*6.4*	*6.2*	*6.0*	*5.8*	*5.7*	*5.4*	*5.2*	*4.8*	*4.6*	*4.4*	*3.8*	*3.3*
190	98	96	94	92	90	88	85	84	82	80	78	76	75	73	71	69	68	66	65	63	62	60	58	57	56	54	53	51	50	49	46	44	42	39	37	32	28
	---	*18.5*	*16.9*	*15.2*	*14.2*	*13.4*	*12.7*	*12.0*	*11.4*	*10.9*	*10.5*	*10.0*	*9.6*	*9.2*	*8.9*	*8.6*	*8.2*	*7.9*	*7.7*	*7.4*	*7.2*	*7.0*	*6.8*	*6.6*	*6.4*	*6.2*	*6.0*	*5.9*	*5.7*	*5.5*	*5.3*	*5.0*	*4.8*	*4.5*	*4.4*	*3.8*	*3.3*
200	98	96	94	92	90	88	86	84	82	80	79	77	75	74	72	70	69	67	66	64	63	61	60	58	57	55	54	53	52	51	48	46	43	41	39	34	30
	---	*18.1*	*16.4*	*14.9*	*14.0*	*13.2*	*12.4*	*11.8*	*11.2*	*10.8*	*10.3*	*9.8*	*9.4*	*9.1*	*8.8*	*8.4*	*8.1*	*7.7*	*7.5*	*7.2*	*7.0*	*6.9*	*6.6*	*6.4*	*6.2*	*6.0*	*5.9*	*5.7*	*5.6*	*5.4*	*5.2*	*4.9*	*4.7*	*4.5*	*4.3*	*3.8*	*3.3*
210	98	96	94	92	90	88	86	85	83	81	79	78	76	75	73	71	70	68	67	65	64	63	61	60	59	57	56	54	53	52	50	47	45	43	41	36	32
	---	*17.7*	*16.0*	*14.6*	*13.8*	*13.0*	*12.2*	*11.7*	*11.1*	*10.6*	*10.0*	*9.7*	*9.2*	*9.0*	*8.7*	*8.3*	*8.0*	*7.6*	*7.4*	*7.1*	*6.9*	*6.8*	*6.5*	*6.3*	*6.1*	*5.9*	*5.8*	*5.5*	*5.4*	*5.3*	*5.1*	*4.8*	*4.6*	*4.4*	*4.2*	*3.7*	*3.2*

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[1] Relative humidity values in roman type.

[2] Equilibrium moisture content values in italic type.

Instruments recording humidity directly are not commonly used in lumber dry kilns. Usually, instruments adapted for this purpose record wet- and dry-bulb temperatures from which relative humidities may be determined. It is obvious, of course, that such a record can be secured by the use of two separate recording thermometers, one suitably equipped with a wet wick over the bulb. It is just as obvious that a better arrangement would be to have both records on the same chart, and this is a very common type of recorder. These instruments are known also as wet- and dry-bulb recording thermometers, recording psychrometers, and recording hygrometers. In principle, temperature-humidity recorders, usually designed for ordinary atmospheric temperatures, are similar to recording thermometers, there being two complete components in a single case, one to record temperature and the other humidity.

Two types of wet bulbs are used in dry-kiln work, the well-known wick-and-water-trough type and the porous-sleeve type. In the latter, a porous sleeve of alundum or other suitable material, which surrounds the wet bulb, is kept filled with water. The water, gradually seeping through the porous walls, is evaporated on the sleeve surface, producing the necessary depression of temperature in the sleeve and the contained bulb. Both types are thoroughly reliable and satisfactory under proper operating conditions. Hard water soon clogs up the porous sleeves, just as it encrusts the wicks, but the sleeves can be cleaned very easily by immersing them in muriatic (hydrochloric) acid, and the wicks can be changed at slight trouble and expense.

5.013. Moisture Content of Seasoned Lumber. The trade terms "green," "shipping dry," "air dry," and "kiln dried," although widely used, have no specific or agreed meaning with respect to moisture content except in a few cases where lumber association rules define moisture content limits for kiln-dried and air-dried stock. The wide limitations of these terms as ordinarily used are covered in the following statements, which, however, are not to be construed as exact definitions:

"Green lumber"—lumber that may be freshly cut or partially seasoned but which has not yet reached a shipping-dry or air-dry condition. The term may also be applied to material that has a higher moisture content than is acceptable for stock being manufactured into finished products.

"Shipping-dry lumber"—lumber that has been partially dried, either in a kiln or by air drying, to reduce weight and freight charges, and which may have a moisture content of 30 percent or more.

"Air-dry lumber"—lumber that has been exposed to the air for any length of time. If exposed for a sufficient time, it may have a moisture content ranging from 6 percent, as in summer in the arid Southwest, to 24 percent, as in winter in the Pacific Northwest. For the United States as a whole, the minimum moisture content range for thoroughly air-dry lumber is 12 to 15 percent in the summer, and the average is somewhat higher. Sometimes terms such as "90 days on sticks" or "4 months in the yard" are used instead of "air-dry" to denote length of time in the yard piles. Since stock seasons slowly in cold weather, less drying would take place during the winter than during the summer, and a given period in the yard would not mean the same degree of seasoning in cold or wet months as would occur in summer or dry months (table 5–3).

TABLE 5–3.—*Approximate moisture content in percent of thoroughly air-dry 1-inch stock by months for different regions*

Forest region [1]	January	February	March	April	May	June	July	August	September	October	November	December
California pine	20	18	16	14	12	10	9	9	10	12	16	18
Redwood	24	25	22	20	18	16	15	15	16	17	19	21
Inland Empire [2]	20	20	18	15	14	14	12½	13	14	15	20	20
Oregon and Washington	26	24	22	18	16	15	12	13	15	16	22	26
Southern pine	20	----	----	13	----	----	14	14	14	16	17	20

[1] In the arid Southwest during the driest portion of the year air-dry lumber dries down to between 5 and 10 percent moisture content.

[2] Northwestern Montana, Idaho north of the Salmon River, Washington east of the Cascade Mountains, and the northeastern tip of Oregon.

"Kiln-dried lumber"—lumber that has been kiln dried for any length of time. The term applies to stock dried to "shipping dry," as defined above, as well as to stock dried to a final moisture content of 8 to 12 percent. Specifications covering kiln-dried lumber intended for immediate processing into a finished product should state the average moisture content, tolerance of individual pieces above and below the average, and moisture distribution between surface and center. For airplane stock, where maximum strength is a factor, it is also necessary to specify the maximum temperatures permissible at various stages of seasoning. Such limits apply of course, even to stock dried to a shipping-dry condition.

5.014. Coatings that Prevent End Checks. Wood dries more rapidly from the end grain than from the side grain, and is apt to check and split during seasoning unless end drying is retarded. For this reason it is advisable to use a moisture-resistant end coating on wood during air seasoning or kiln drying, especially on woods which are difficult to dry and on short kiln samples. As end checks, once started, are hard to stop, such coatings should be applied as soon as possible to the freshly cut ends.

The coatings ordinarily used are of two kinds. Those of the first kind are liquid at ordinary temperatures and can be applied cold; the second are solid at ordinary temperatures and must be applied hot. Cold coatings have the advantage that they may be used as easily on logs and lumber as on kiln samples and dimension stock; hot coatings, because of the usual method of application (end dipping), are not easy to use on large stock.

Either cold or hot coatings can be used in the kiln, but each type has its advantages and disadvantages. Hot coatings should have a melting point sufficiently high to prevent a breakdown in their efficiency under the kiln temperatures used. In general, this requires a melting point approximately 30° to 40° F. above the kiln temperatures. Hot coatings, as a type, are very water resistant and, when properly used, are more effective than the cold coatings.

Excessive shrinkage of the wood and rough handling often cause the end coatings to chip or shear off, and a fresh application of the coating should then be made. To reduce end drying sufficiently, there should be a thick unbroken coating over the entire end surface. Hot coatings are usually applied by dipping the wood approximately one-half inch into the liquid or by firmly pressing and rolling the end surface over a free or, preferably, a power-driven roller, the lower portion of which extends into the hot coating. Cold coatings should have about the consistency of heavy syrup, and are usually applied by brush. They should be allowed to dry a few hours before being subjected to kiln temperatures.

The two best cold coatings developed at the Forest Products Laboratory are hardened gloss oil thickened with barytes and magnesium silicate (very cheap), and a mixture of phenolic-resin varnish and aluminum powder or paste. The latter coating is expensive, but when two coats are applied it is very effective and has some advantage over the former.

The manufacture of hardened gloss oil involves technical operations and should not be attempted by the novice. Because gloss oil is made commercially in a number of ways, and because some of the products are unsuited for end coatings, a gloss oil should be specified that is made in accordance with the following formula:

6 to 8 parts by weight hydrated lime.
100 parts by weight rosin.
57.5 parts by weight mineral spirits.

To 100 parts by weight of this gloss oil add 25 parts barytes and 25 parts magnesium silicate. One or two parts of lampblack may also be added if a black coating is desired. The magnesium silicate helps to keep the pigment in suspension. In time, however, it will settle, and the spirits will evaporate. As a result of these two actions, the filled hardened gloss oil tends to become pasty if allowed to stand any considerable period. It is suggested, therefore, that the user protect his gloss oil from evaporation and mix relatively small quantities of it with the barytes and magnesium silicate as needed.

Paraffin has proved very satisfactory as an end coating for stock during air seasoning, but cannot be used in the kiln because of its low melting point. The following hot coatings are satisfactory for all ordinary kiln temperatures:

(1) Coal-tar pitches or asphalts with melting points between 195° and 213° F.

(2) Mixtures of such coal-tar pitches and asphalts. (For instance, 100 parts by weight of 213° and 40 parts of 155° F. coal-tar pitch plus 25 parts of 220° asphalt.)

(3) Rosin and lampblack (100 parts by weight of rosin to 7 parts of lampblack).

(4) Any mixture of high-melting-point pitches and rosin.

5.02. Care and Shipment of Lumber Prior to Seasoning. Under favorable temperature conditions, the sapwood of green lumber is subject to attack by mold- and stain-producing organisms if left in solid piles for several hours before stacking for drying. Even the heartwood of some species may be affected. Protective measures require quick transfer from the mill to the kiln or air-seasoning piles. Some species (*5–2*) are more susceptible than others and require special measures of protection, such as end-racking, for 2 or 3 days before piling in the yard, or dipping in toxic solutions as the stock passes on the green chain along the sorting table.

Stain and mold fungi usually do not grow below a temperature of 35° F. and above a temperature of 100° F., but the most favorable conditions range between 75° and 85° F.

Green stock piled in freight cars is subject to the same hazards as solid piles at the mill, aggravated, however, by the fact that the time element is greatly extended, and that there is practically no ventilation around the piles. Green stock might be safely shipped if it is cut during cold weather and the temperatures during transit remain low enough to prevent the growth of fungi. Stock having a maximum moisture content of 20 percent will not support the growth of fungi and usually may be shipped safely. The possibility of stain developing in solid piles of lumber containing sapwood is affected by three factors—temperature, moisture content, and time. It is customary trade practice to ship stock called "shipping dry" both on ships and in freight cars. Such stock may have a moisture content of 20 percent or more, and with favorable temperatures may stain and mold in transit.

Stacking green lumber on stickers in a closed freight car does not prevent stain, but dipping such stock in a toxic solution and then stacking it in a closed car does provide considerable protection even if the stock is bulk-piled.

Stacking lumber on flat cars, either solid or on stickers, has many disadvantages. Unless it is protected by cover boards or waterproof paper, serious damage from checking usually results. If so protected, the problems are much the same as in closed cars.

If emergency conditions require the shipping of green lumber under conditions liable to cause stain or decay, the stock should be dipped in an antistain solution and, after arrival at destination, the lumber should be unloaded at once and kiln dried or stacked for air seasoning as described in section 5.03. If stain or decay already is present, the lumber should be placed in a kiln and steamed as described in section 5.04.

5.03. Air Seasoning. Seasoning practices differ materially in the various timber-producing regions, and also as between hardwoods and softwoods even in the same locality (*5–3*). Generally hardwoods are air dried before shipment, whereas often the upper grades of softwoods are kiln dried green from the saw. It may be necessary to carry a surplus stock of lumber to insure against shortage at the time of manufacture. If the stock is green, advantage may be taken of this intermediate period to reduce the moisture content, thereby reducing the time required for kiln drying. At softwood mills, the lower grades and dimension are usually air dried. Since most air-dried stock used in airplane products will be kiln dried, it follows that the quality of the finished product depends in no small measure upon the care taken in the preliminary air seasoning.

Piling that is correct for air seasoning must accomplish a number of objectives: It must provide proper air circulation, it must offer suitable protection from sun and rain, and it must keep boards straight and flat while they are drying. If these things are accomplished, the best drying will result and drying defects will be at a minimum. Among such defects may be mentioned stain and decay, end and surface checking, and warping. No one rule will apply to all weather conditions and to all classes of stock; some species must be open piled to hasten drying and thereby avert stain, while others must be close piled to prevent too rapid drying, which may cause checking. The following general principles will apply to most seasoning yards.

5.030. Stain Prevention. If stain is likely to occur, freshly cut lumber containing sapwood should be dipped in or sprayed with an antistain solution for protection against fungi attacks during the air-seasoning period (*5–5*).

5.031. Foundations. The pile foundations (pile bottoms) should be constructed as follows:

(a) The foundations should be rigid and properly leveled.

(b) The foundations should be high enough from the ground to allow good circulation. The minimum distance from the ground to the under side of the lumber at the rear of the pile should be 18 inches.

(c) Foundations should slope from front to rear about 1 inch to the foot.

(d) Material for piers is listed in order of durability and should be so selected whenever available:

Concrete or masonry.
Pressure-creosoted blocks of any species or the heartwood of baldcypress, redwood, or cedar. (When untreated woods are used, all points of contact should be given two coats of hot creosote.)

(e) Beams and stringers should preferably be of steel, or pressure-creosoted timbers. Untreated durable woods with two coats of hot creosote at points of contact may be used when either of the first two are not available.

(f) If existing pile bottoms are to be used, they should be inspected to see that they comply with the requirements given as to height levels and drainage conditions. All weeds, debris, and decayed wood and vegetation must be cleared away. Any part of the pile bottom containing decay should be removed or the decayed area cut out. All wood parts should be painted with two coats of hot creosote.

5.032. Air Flues. The following minimum requirements should be followed:

(a) Even-width stock should have space between the boards or planks not less than 20 percent of the width of the board. The boards in each succeeding layer should be placed directly over those below so that the spaces between boards will form uninterrupted vertical flues.

(b) The lateral spacing between the edges of boards or of groups of boards totaling 12 to 14 inches in width should be at least four inches, so arranged as to form straight vertical flues in the pile; or in uneven-width material one tapering flue not less than 12 inches at the bottom should be used for a 6-foot pile, and two such flues in wider piles. With the tapering flue, the space between adjacent tiers of boards should be not less than 1 inch.

5.033. Stickers. The following minimum requirements should be followed:

(a) All stickers must be sound, thoroughly dry, free from stain, and of uniform thickness.

(b) Each tier of stickers should be aligned and rest on a beam.

(c) Stickers for 4/4-inch lumber should be of nominal inch stock or thicker and not more than 4 inches wide. For thicker lumber of random length, stickers should be at least 1½ inches thick for greater stiffness and strength and not more than 4 inches wide.

(d) Stickers should overlap the ends of the boards at least ½ inch to reduce end checking.

(e) Stickers should not be more than 2 feet apart for hardwoods up to 6/4 inch in thickness. For thicker hardwoods and all softwoods, the equivalent of five rows of stickers for 16-foot stock should be used.

(f) Aircraft stock should never be self-stickered.

5.034. Placing of Lumber. The following minimum requirements should be followed:

(a) Piles should be erected of boards of equal length wherever practicable.

(b) Box piling should be used for mixed lengths. With this system, the longest stock is piled in the outer rows and short lengths within the pile, with one end of a board at one end of the pile and one end of the adjacent board at the opposite end. In each succeeding layer, the outside ends of boards should be kept immediately over the ends of those below.

(c) Each layer should be composed of boards of the same thickness.

(d) The pile should have a forward pitch to the extent of 1 inch for each foot of height and a slope from front to rear of 1 inch for each foot of length.

(e) Narrow piles are desirable for stock that will withstand rapid drying and wide piles for stock that is liable to check and honeycomb. Common pile widths range from 6 to 16 feet.

(f) The lateral space between piles should be at least 4 feet, and the distance between the rear ends of the piles should be at least 8 feet.

5.035. End Coatings. End coatings should be applied in all cases where end checking is objectionable. Several satisfactory end coatings are listed under section 5.014.

5.036. Covering. All material should be under cover either in an open shed or with roofs over individual piles. One satisfactory type of pile roof consists of two layers of low-grade boards, those in the upper layer being staggered with respect to those in the lower layer.

(a) A minimum front height of 6 inches above the lumber, with a slope of at least 1 inch to the foot, should be required.

(b) The ends and the sides should project sufficiently to prevent snow and rain from beating into the lumber piles.

(c) The roof should be securely fastened.

5.037. Site. The yard should be well drained and kept free of weeds and debris.

5.04. Kiln Drying of Lumber. Lumber is kiln dried, first, to reduce moisture more quickly than in air drying, and, second, to reduce the moisture content to a lower point than can ordinarily be attained in air drying. In addition, if stain, decay organisms, or wood-boring insects are present, the lumber will usually be sterilized and the borers killed.

5.040. Essentials of Good Kiln Drying. Lumber intended for airplane parts requiring maximum strength and minimum dimensional changes after manufacture must be free from surface or end checks, honeycomb, case-hardening, and warp, and the moisture content and moisture distribution must be within the range best suited for conditions of service. Properly designed kilns have both temperature and humidity under automatic control so that the optimum conditions of drying can be maintained during the seasoning period. Circulation of air, adequate in both uniformity and volume, is necessary for good control of temperature and humidity. The initial drying period, during which the stock is green, is the most critical stage or time that the stock is most likely to be damaged. It is during this period that the lowest temperatures and highest humidities are needed and uniformity of control can be obtained best with the aid of fans, blowers, or other mechanical means of stimulating circulation. After stock has been dried to a moisture content of 25 percent or lower, less circulation is required to obtain accurate control of the drying.

In double-track kilns in which air enters at one side wall, passes through the piles on both tracks and thence into the space between the load and the opposite wall, a small heating coil is sometimes located in the space between the two loads. The object is to make up the heat loss that develops as the air passes through the first load. These booster coils, while acceptable in standard commercial drying, are not desirable as a rule for the drying of airplane stock. Their use should be permitted only after examination to determine if they cause excessive temperatures.

5.0400. Material:

(1) Species of the same drying characteristics may be included in the same charge.

(2) Pieces should be dried in the smallest sizes to be used and which are practical to handle, rather than in large dimensions.

(3) Reasonable variations of thickness may be tolerated if drying conditions are regulated for the wettest, thickest, and slowest drying stock and care is taken to give each thickness its proper final conditioning treatment.

5.041. Temperature and Relative Humidity. The specifications define maximum temperatures for various species of lumber at different stages of drying and the bulbs of the recording hygrometer and control bulbs of the thermostats should be located, if practical, where they will measure the most severe drying conditions. In reversible-circulation kilns, dual dry bulbs or other acceptable means of controlling the temperature of entering air should be used.

Maximum temperatures are tabulated in the specification because temperatures in excess of the values allowed for different degrees of dryness are likely to reduce the strength of the wood. Relative humidities at permissible kiln temperatures have no deleterious effects on the strength of the wood as long as they are high enough to prevent checking and honeycombing; hence, the humidity schedule is left to the discretion of the kiln operator. For the kiln operator who has had no experience in drying a given item of aircraft lumber, the relative humidity schedules in tables 5–4 to 5–8 are offered as a guide. In general, they are conservative, and experience with a particular kiln should afford a basis for improving them.

TABLE 5–4.—*Suggested relative humidities*[1] *for temperatures specified in schedule 2 of AN–W–2a*

Species	Thickness	Percent moisture content at which changes are made—						
		Above 40	40 to 30	30 to 25	25 to 20	20 to 15	15 to 10	10 to final
	Inches	*135° F.*	*140° F.*	*145° F.*	*150° F.*	*155° F.*	*160° F.*	*165° F.*
Noble fir	1	65	60	55	50	45	35	35
Red pine	1	70	60	50	45	40	35	35
Red spruce	1	75	60	50	45	40	35	35
Sitka spruce	1	75	60	50	45	40	35	35
White spruce	1	75	60	50	45	40	35	35
Port Orford white-cedar	1	75	60	50	45	40	35	35

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[1] In 10-inch and wider flat-grain softwoods, relative humidities approximately 10 percent higher should be used during the first 2 schedule periods. In drying aircraft lumber in a natural-draft kiln, the relative humidities suggested in this table may be reduced about 5 percent.

TABLE 5–5.—*Suggested relative humidities for temperatures specified in schedule 3 of AN–W–2a*

Species	Thickness	Percent moisture content at which changes are made—						
		Above 40	40 to 30	30 to 25	25 to 20	20 to 15	15 to 10	10 to final
	Inches	*130° F.*	*135° F.*	*140° F.*	*145° F.*	*150° F.*	*155° F.*	*160° F.*
Douglas-fir	1	70	65	60	50	40	35	35
Red fir	1	65	50	40	40	35	35	35
Sugar pine	1	60	50	40	40	35	35	35
Silver maple	1	80	75	70	60	50	40	35
Sugar maple	1	80	75	70	60	50	40	35
Yellowpoplar	1	80	75	70	60	50	35	35
Noble fir	1½	65	60	55	50	45	35	35
Red pine	1½	75	70	50	45	40	35	35
Sitka spruce	1½	75	70	50	45	40	35	35
Red spruce	1½	75	70	50	45	40	35	35
White spruce	1½	75	70	50	45	40	35	35
Port Orford white-cedar	1½	80	65	50	45	40	35	35
Silver maple	1½	80	75	70	60	50	40	35
Sugar maple	1½	80	75	70	60	50	40	35

Table 5-6.—*Suggested relative humidities for temperatures specified in schedule 4 of AN-W-2a*

Species	Thickness	Percent moisture content at which changes are made—						
		Above 40	40 to 30	30 to 25	25 to 20	20 to 15	15 to 10	10 to final
	Inches	*125° F.*	*130° F.*	*135° F.*	*140° F.*	*145° F.*	*150° F.*	*155° F.*
Baldcypress	1	70	50	45	40	35	35	35
Baldcypress	1½	75	50	45	40	35	35	35
Western hemlock	1	65	60	55	50	45	35	35
Eastern white pine	1	60	55	50	45	40	35	35
Ponderosa pine	1	60	55	50	45	40	35	35
Western white pine	1	60	55	50	45	40	35	35
Black walnut	1	80	75	70	65	55	45	35
Black walnut	1½	80	75	70	65	55	45	35
Douglas-fir	1½	70	65	60	50	40	35	35
Red fir	1½	70	60	50	40	35	35	35
Sugar pine	1½	65	55	50	50	40	35	35
Yellowpoplar	1½	80	75	70	60	50	35	35
Noble fir	2	75	60	55	50	45	35	35
Red pine	2	80	75	55	50	45	35	35
Red spruce	2	80	75	55	50	45	35	35
Sitka spruce	2	80	75	55	50	45	35	35
White spruce	2	80	75	55	50	45	35	35
Port Orford white-cedar	2	80	75	60	50	45	35	35

Table 5-7.—*Suggested relative humidities for temperatures specified in schedule 5 of AN-W-2a*

Species	Thickness	Percent moisture content at which changes are made—						
		Above 40	40 to 30	30 to 25	25 to 20	20 to 15	15 to 10	10 to final
	Inches	*120° F.*	*125° F.*	*130° F.*	*135° F.*	*140° F.*	*145° F.*	*150° F.*
Commercial white ash	1	80	75	70	60	50	35	35
Commercial white ash	1½	80	75	70	60	50	35	35
Yellow birch	1	80	75	70	60	50	35	35
Yellow birch	1½	80	75	70	60	50	35	35
Black cherry	1	80	75	70	65	55	45	35
Black cherry	1½	80	75	70	65	55	45	35
Khaya (African mahogany)	1	80	75	70	60	50	40	35
Khaya (African mahogany)	1½	80	75	70	60	50	40	35
West Indies mahogany	1	80	75	70	60	50	40	35
West Indies mahogany	1½	80	75	70	60	50	40	35
Baldcypress	2	80	75	50	45	40	35	35
Douglas-fir	2	75	70	60	50	40	35	35
Ponderosa pine	1½	65	50	50	45	40	35	35
Red Fir	2	75	60	55	50	45	35	35
Sugar pine	2	70	50	45	40	35	35	35
Yellowpoplar	2	85	75	70	60	50	35	35
Red spruce	3	90	75	70	50	45	35	35
Sitka spruce	3	90	75	70	50	45	40	35
White spruce	3	90	75	70	50	45	40	35
Port Orford white-cedar	3	90	75	70	50	45	40	35
Eastern white pine	1½	65	55	50	45	40	35	35
Western white pine	1½	65	55	50	45	40	35	35

TABLE 5–8.—*Suggested relative humidities for temperatures specified in schedule 6 of AN–W–2a*

Species	Thickness	Percent moisture content at which changes are made—						
		Above 40	40 to 30	30 to 25	25 to 20	20 to 15	15 to 10	10 to final
	Inches	*115° F.*	*120° F.*	*125° F.*	*130° F.*	*135° F.*	*140° F.*	*145° F.*
Sweetgum	1½	80	75	70	60	50	35	35
Western hemlock	2	80	70	50	50	40	35	35
Western hemlock	3	85	70	60	55	45	35	35
Eastern white pine	2	80	70	50	50	40	35	35
Ponderosa pine	2	70	50	50	45	40	35	35
Ponderosa pine	3	80	60	55	50	40	35	35
Red pine	3	85	60	55	50	40	35	35
Sugar pine	3	70	60	55	50	40	35	35
Western white pine	2	70	50	45	40	35	35	35
Yellowpoplar	3	85	80	75	65	55	40	35
Red spruce	3+	85	80	50	45	40	35	35
Sitka spruce	3+	85	80	50	45	40	35	35
White spruce	3+	85	80	50	45	40	35	35

The relative humidities in the last stage of drying can be lowered with safety as far as checking is concerned, but such a reduction will tend to increase the range in final moisture content values.

5.042. Piling. The method of piling should be suited to the circulation system of the kiln in which the stock will be dried. Two general methods of piling are used: edge stacking, with the stock standing edgewise in the kiln truck with the edges touching, the faces of the board separated with vertical stickers, and the circulation intended to be up or down through the open spaces between the faces of the boards; and flat stacking, with the stock laid flat in the load, spaces provided between boards, and stickers laid horizontally. The latter method is preferred, because it tends to hold the lumber more nearly flat; circulation may be vertical, horizontal, or a combination of both directions.

These two methods of piling are applicable to either natural- or forced-circulation types of kilns.

In natural-circulation kilns the air movement is generally downward through the load when the stock is relatively green and upward when nearly dry. In edge stacking, the pile provides the vertical flues suited to this air movement. For flat stacking in natural-circulation kilns, the lateral spacing between the edges of boards or of groups of boards totaling 12 to 14 inches in width should be at least 4 inches, so arranged as to form straight vertical flues in the pile. In piles 5 feet or more in width, a vertical flue may be provided also in the middle of the load at least 8 inches wide from the bottom of the pile.

In forced-circulation kilns, the design of the kiln usually determines the method of piling best adapted to the circulation system.

(1) Nominal 1-inch stickers should be used for all edge-piled stock and for flat-piled stock up to 6/4 inch in thickness, and 1½-inch stickers for random length stock thicker than 6/4. In flat piling, the stickers must be in vertical alinement, not more than 2 feet apart for 6/4-inch stock and not more than 4 feet apart for stock thicker than 6/4. All sticker tiers must bear on beams or cross ties.

(2) Each layer should consist of boards of the same thickness.

(3) Piling should be so done as to avoid overhanging ends of boards. At least 24 inches should be allowed between the loads and the side walls.

(4) Box piling should be used for flat-piled stock of mixed lengths. With this system, the longest stock is piled in the outer rows and short lengths within the pile, with one end of a board at one end of the pile and one end of the adjacent board at the opposite end. In each succeeding layer, the outside ends of boards should be kept immediately over the ends of those below.

5.043. Steaming. Any operating condition, at or above operating temperatures, using humidities high enough to prevent drying, or that would add moisture to the stock, may be defined as steaming. It is not good practice to give air-dried wood an initial steaming treatment. When necessary to sterilize wood to kill mold or stain, an initial steaming treatment may be given; otherwise, both green and air-dried wood should be started off at the initial temperature and relative humidity of the drying schedule. During the period while the kiln and the load are being heated to operating conditions, the wet-bulb depression established by the schedule should be maintained as closely as possible.

Throughout the drying period the surface of the stock is consistently at a lower moisture content than the center. Early in the drying operation there may be a wide difference, but near the end of the drying period the difference decreases Stock dried to 6-percent moisture content would have less variation between outer portion and core than exists when the moisture content averages 12 percent. Since the specifications limit the acceptable difference in moisture distribution, the operator must plan his final operating conditions to suit the final average moisture content of the charge. In principle, it will be necessary first to determine the average moisture content at which the charge is to be unloaded, then to carry the average moisture content of the load below that value to bring the moisture content of the core within the allowable limits, and finally, through the use of higher humidities, to build up the surface moisture content slightly to establish the desired average. This final steaming (conditioning) treatment will also be valuable in reducing casehardening stresses. The limiting conditions during final conditioning periods are specified in AN–W–2a.

A conditioning treatment at or near the end of the run will usually be necessary to bring about uniformity of moisture content distribution in each board and to relieve severe casehardening stresses. Casehardened stock should be conditioned at a temperature not over 74° C. (165° F.) and at humidities that will permit the stock to pick up not more than 2 percent of moisture, based on the average moisture content of the kiln samples; but in no case should the humidity be such as to produce stock having a moisture content value less than 8 percent or more than 12 percent. The conditioning treatment should continue long enough to relieve the stresses and bring about the specified degree of moisture uniformity in each piece. The usual time necessary is approximately 5 hours per inch of thickness for softwoods and from 18 to 24 hours per inch for hardwoods. In order that these conditioning treatments at or near the end of the run may be most effective, it is necessary that the range of moisture content in the boards making up the kiln charge be as small as possible.

5.044. Selection of Samples. The kiln operator should use great care and judgment in selecting material for use as kiln samples and in locating the samples in the kiln charge so that they will fully represent the conditions of the charge during the drying operation. The specifications require that there shall be at least 12 samples, six from each of two boards, for each kiln charge and that they represent the wettest and slowest drying class of material. In mixed thicknesses or mixed species, additional samples of the faster-drying stock may prove of value as well as additional random samples representing the heavy boards. When samples are prepared, the ends should be coated as soon as possible after cutting to prevent end drying. Moreover, they should be protected against rapid drying before they are placed in the pile or kiln charge.

5.045. Tests at End of Drying Period. Regardless of the care used in preparing samples, errors are sometimes made; at the end of the run, therefore, the samples

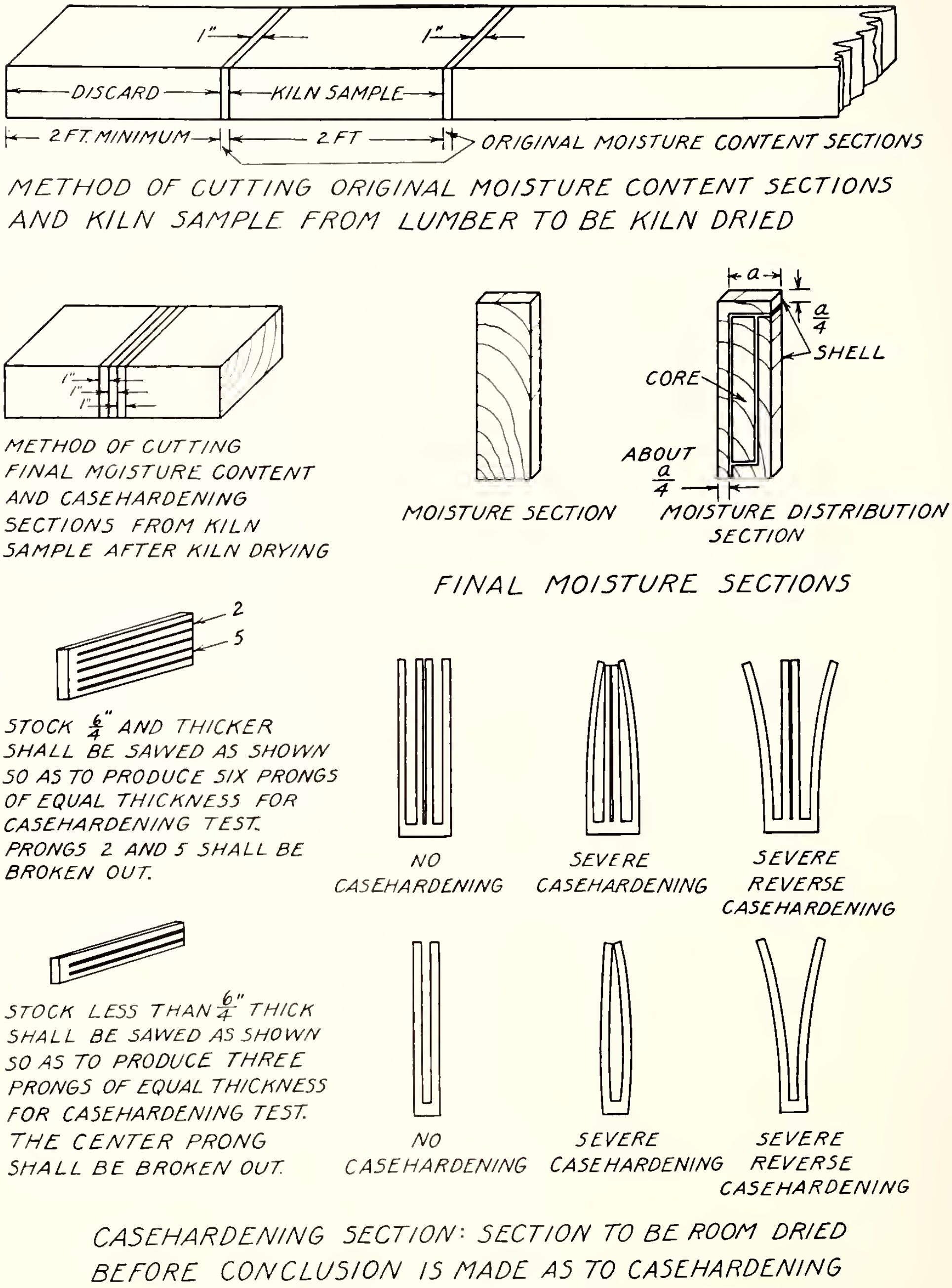

FIGURE 5-3.—Kiln sample and test sections for moisture content and casehardening.

should be rechecked by cutting new moisture content sections. At the same time, moisture distribution and casehardening tests can be made. Where necessary to make distribution tests before final steaming, only part of the samples should be cut up and the others used to guide the steaming operation and to check the results after steaming.

A casehardening test indicates (1) the presence and degree of stresses within the piece at the time of sawing and (2) the influence of unequal moisture distribution (*5–6*). Methods of preparing both thick and thin stock for casehardening tests are shown in figure 5–3. These sections are to be room-dried for 24 hours or until moisture content is uniform, in order that the stresses present become discernible in the prongs. All casehardening test sections should be numbered with an indelible pencil to correspond to the number of the kiln run. Casehardening is indicated when the prongs turn in or cup toward the saw when being cut. Reverse casehardening is caused by over-conditioning at too high a relative humidity and is indicated when the prongs turn away from the saw. Both represent the tendency of the same stock to cup if resawed. Planing, routing, or working up of casehardened stock may unbalance the stresses and result in warping. Unequal moisture distribution is indicated when the prongs turn in after room-drying. The effects are similar to casehardening, except that the distortion does not occur at the time of machining but afterward, when the moisture content has become equalized. Both casehardening and moisture distribution tests are required before the stock is taken from the kiln so that the proper treatment can be given before the stock is unloaded.

Another casehardening test may be made in the following manner when the purpose to which the stock will be put is known:

Cut the test section on a band saw to simulate the finished cross section or profile the piece would have after manufacture. Place the section in a factory workroom for 24 hours, or until the moisture content is uniform. Any distortion is evidence of casehardening or lack of uniformity of moisture distribution and indicative of the change in shape which would have occurred had the stock been worked up while in the condition represented by the section. If the distortion exceeds that allowed for the member or part, the stock should be subjected to a relative humidity sufficiently high to relieve the stresses.

5.046. Example. Stock intended for propeller use is too thick, and after jointing one face the excess will be dressed off the other. As the depth of the cut on opposite faces would not be equal, the casehardening stresses would become unbalanced and, if of sufficient intensity, would cause the piece to cup toward the face having the deeper cut. This condition may be simulated in a casehardening test by removing wood from one side of the section, equal to the jointing operation, and a greater amount from the opposite face. The amount of distortion which would follow after room-drying would indicate whether the stock would be acceptable for the purpose.

5.047. Kiln-drying Defects. The following is a brief description of the principal defects in kiln-dried lumber:

5.0470. Surface Checks. Surface checks weaken the member and cannot be permitted in finished parts. Surface checks in rough stock which can be dressed out or will not appear in the finished piece will not be cause for rejection. Surface checks may be closed and invisible. To test for closed checks, cut a 1-inch section out of the board and then cut prongs one-eighth inch in thickness parallel to the wide face of the board. If checks are present, the prongs will fall off where checked.

5.0471. Honeycomb. This defect may be considered as an internal check, usually developing along the rays. It may be preceded by a surface check which closes as drying progresses because of tension from within. Honeycomb may also develop in stock not previously surface checked. Too high temperatures and severe casehardening are the most common causes. It may also occur if severely casehardened stock is steamed at 100 percent relative humidity. The moisture pick-up on the surface will cause increased internal tension stresses; and when the stress exceeds the strength of the wood substance, honeycomb develops. Honeycomb is cause for rejection. Figure 5–4 shows severe honeycombing in an oak plank.

5.0472. Collapse. This is abnormal shrinkage, causing grooves to appear in the surface of the lumber. It sometimes occurs when wet lumber is dried at too high a temperature. Woods which are especially subject to collapse are western redcedar, redwood, sweetgum, and white oak. All collapsed stock should be rejected. Collapse in western redcedar is shown in figure 5–5.

5.0473. Brashness. When lumber is subjected to very severe temperatures, whether in dry or moist air, the wood will be darkened in color and become brash. This weakening effect increases with an increase in either temperature or time. If the schedules given are not exceeded, no difficulties will be encountered insofar as seasoning is concerned. All brash stock should be rejected.

5.0474. Casehardening. Casehardened lumber is that which contains internal stresses caused by unequal shrinkage within the piece. The outer portion is in compression, and the inside is in tension, though these stresses are balanced in the rough piece. Should these stresses become unbalanced, as will occur if the stock is resawed or more dressed off one side than the other, the piece will cup, the amount of cupping depending upon the severity of the stresses. Tests for casehardening are described in section 5.045. Acceptance or rejection of casehardened stock will depend upon the degree of casehardening permissible as outlined therein.

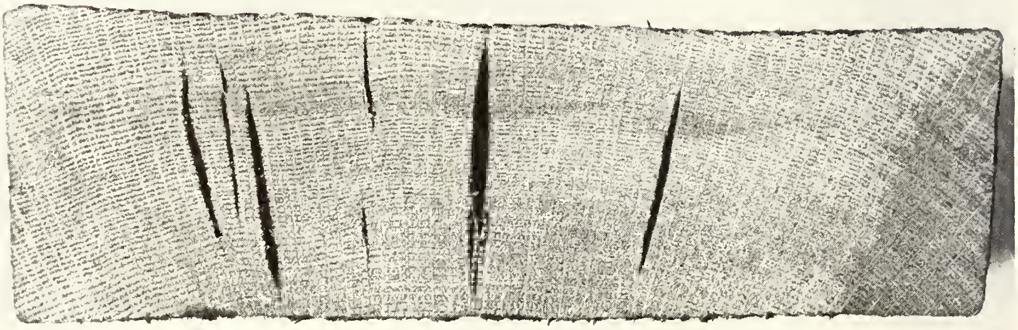

FIGURE 5–4.—End of oak plank showing honeycombing.

5.05. Final Conditioning of Air-dried Stock.

5.050. Preparing Air-dried Stock for Manufacture. Usually air-dried stock is not in satisfactory condition for use in aircraft, and the common procedure is to place it in a kiln for final drying and relief of casehardening stresses. If a kiln is not available or if sufficient storage space in sheds or rooms, heated to or slightly above ordinary factory temperature, is available and time not important, it might prove practical to store air-dried lumber in such rooms until the moisture content complies with the requirements of Specification AN–W–2a. Before use, however, any existing casehardening stresses must be removed by a conditioning treatment, either in a kiln or in a storage room in which it is possible to raise the relative humidity by temperature adjustments or humidification, similar to the kiln method described in section 5.043. Low-temperature conditioning can be accomplished similarly, except that more time will be needed. Stock so dried could then be used without kiln drying. The following rules should be observed in room drying.

5.051. Piling. Pile foundations should be designed to permit circulation below the pile. The lowest layer of lumber should be 18 inches above the floor. Piles should be 2 feet apart, not nearer than 2 feet to outside walls, and not more than 6 feet wide. Stock not over 6/4 inch thick should be placed on 1-inch stickers. For thicker material of random length, 1½-inch stickers should be used for greater stiffness and strength. Stickers should be evenly alined and not more than 2 feet apart for stock up to and including 6/4 inch in thickness and not more than 4 feet apart for stock thicker than 6/4.

5.052. Circulation. Small fans may be used when necessary to bring about a circulation of air sufficient to keep temperatures relatively uniform.

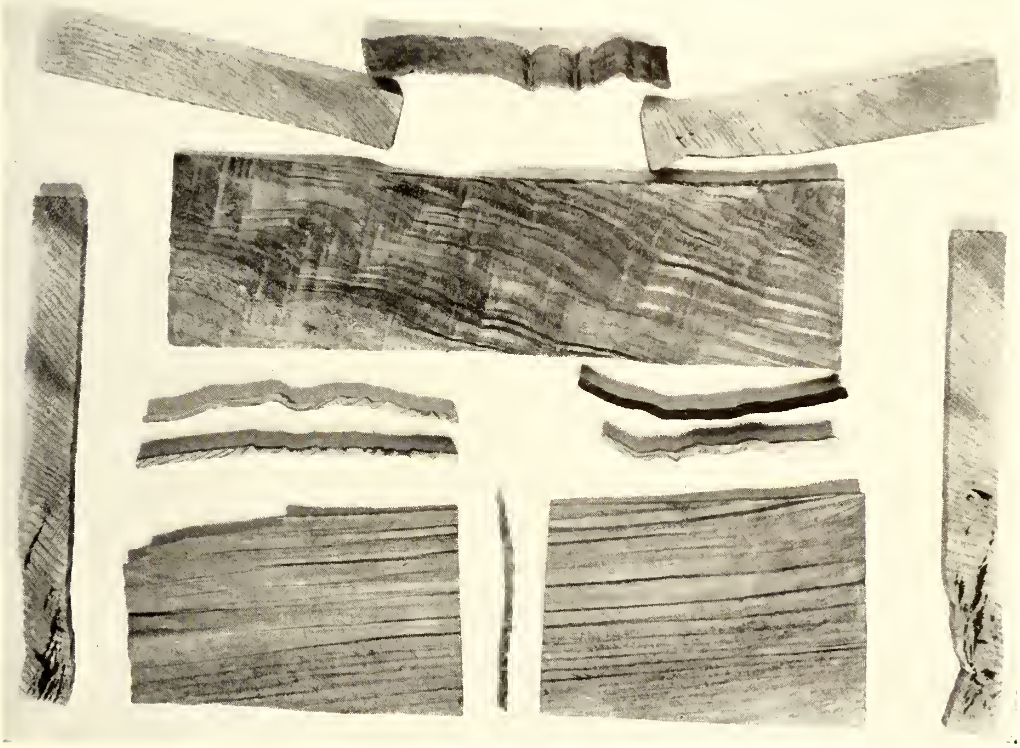

FIGURE 5-5.—Collapse in western redcedar.

5.053. Temperature, Humidity, and Moisture Relations. By referring to the equilibrium moisture content curves (fig. 5-6) one can readily determine the necessary temperature and humidity conditions required to maintain a desired constant moisture content. To hasten the final drying process, the humidity may be 15 percent below that required to maintain the final moisture content specified. In most cases it should be possible to secure the desired temperature and humidity conditions by controlling only the temperature (*5-4*). For conditioning treatments, however, steam or water sprays may be required.

5.06. Storage of Kiln-dried and Air-dried Stock.

5.060. Storage. Aircraft lumber should be dried to meet moisture content and casehardening specifications, and subsequent storage should be relied upon merely to obtain additional benefits in the form of more nearly uniform transverse moisture distribution and further relief of casehardening stresses. For kiln-dried stock, at least 2 weeks' storage is desirable for this purpose, but to maintain the stock in satisfactory condition until used in the shop, the storage conditions should be controlled within the moisture-content range specified. In such cases, the stock can be either left on stickers or solid piled.

Stock stored under uncontrolled conditions may become unsatisfactory regardless of the method of piling, because a longitudinal moisture gradient may develop in a solid pile and a general moisture pick-up may occur in an open pile.

Storage of all material before manufacture should be under conditions that will deliver the stock sound, free from seasoning defects, and at a suitable moisture content. In order to reduce moisture changes or to secure wood at a given moisture content, it may be necessary to equip the storage shed, or factory, with humidity-control equipment so that the range of moisture change may be controlled. The humidity should be so controlled that the moisture content of stock other than propeller material cannot fall below 8 percent or rise above 12 percent. Propeller stock should be stored under conditions that maintain the moisture content at between 5 and 7 percent.

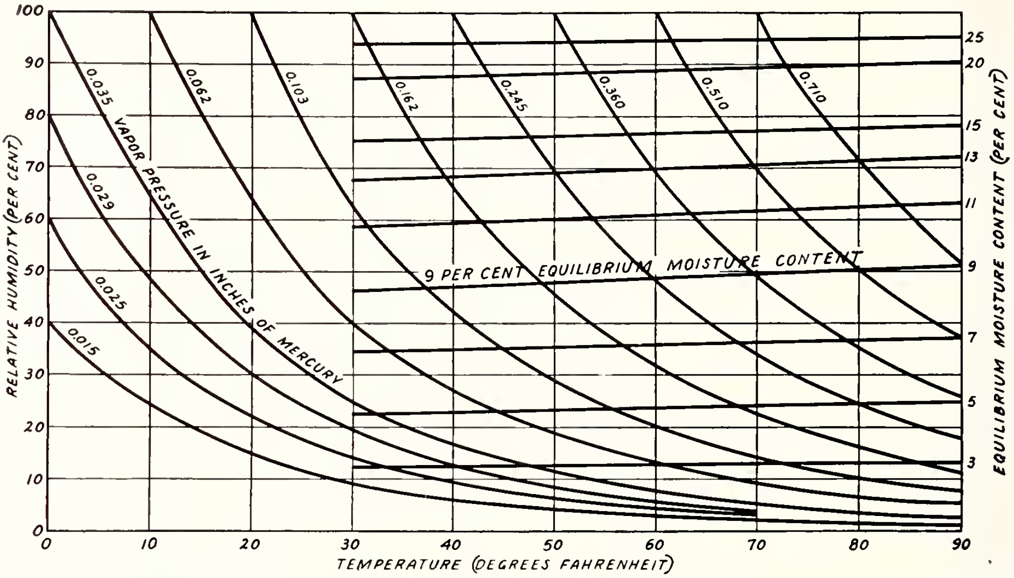

FIGURE 5-6.—Equilibrium moisture content curves. Example: To determine what temperature should be maintained when the outdoor temperature is 30° F., the relative humidity 80 percent, and the desired equilibrium moisture content is 8 percent, proceed as follows: From the intersection of the (vertical) 30°-temperature line and the (horizontal) 80-percent relative humidity line, extend a line midway between the adjacent (concave) vapor-pressure lines until it intersects a line midway between the 7- and 9-percent moisture-content lines indicated on the right-hand ordinate. The reading on the bottom scale at the point of the second intersection is about 47°.

Stock that has been dried to the acceptable moisture content, if kept dry, may be held for an indefinite period without deterioration from seasoning defects, such as checking, honeycombing, stain, and decay.

5.061. Effect of Storage on Insect Attack. Certain woods are subject to insect attack even after drying. The Lyctus powder-post beetle attacks especially the seasoned sapwood of hickory, ash, and oak, and it also damages other hardwoods such as black walnut, maple, black cherry, elm, yellowpoplar, and sycamore. Other powder-post beetles attack both heartwood and sapwood, and both hardwoods and softwoods. Stored stock that is subject to borer attack should be moved in rotation, so that none of it will remain exposed to infestation for an excessively long time.

In addition, such stock should be examined regularly and carefully, and borer-infested stock should be either heat-sterilized or destroyed. Infestation of adjacent stock is merely a matter of time if proper preventive measures are not observed. The larvae of the Lyctus beetles bore inward, giving little or no early indication of their presence and thus making prompt recognition of infestation highly difficult. Borers eat holes from $\frac{1}{16}$ to $\frac{1}{4}$ inch in diameter and leave wood powder in them. When a hole penetrates an exterior surface, the powder can be jarred out. Badly tunneled wood can easily be broken.

5.062. Effect of Heat on Strength Properties of Wood. The effect of temperatures above normal atmospheric on the strength properties of wood has not been fully explored. During and immediately after World War I, extensive studies were made at the Forest Products Laboratory of the effects of kiln drying (*5–7*). These demonstrated that with such temperatures as are specified in AN–W–2a (105° F. to 135° F. at the beginning and 135° F. to 165° F. at the end of the run according to the species and the thickness) and with proper control of relative humidity and other factors, wood could be kiln dried without any deficiency in strength properties as compared to the most carefully air-dried stock. It was also indicated that higher temperatures, if applied for the length of time required for kiln drying, were likely to be damaging, particularly to shock resistance.

The time involved in kiln drying is usually a matter of days or even weeks. It is obviously to be expected that considerably higher temperature may be applied safely when the period of exposure is only a few minutes or a fraction of an hour as in the drying of veneers. In recent tests on Douglas-fir and Sitka spruce, green wood in a thickness of one-eighth inch heated to 320° F. between hot plates for 20 minutes was not deficient in strength properties as compared to matched material that was carefully air dried. Considerably longer heating periods (up to 4 or 5 hours) at this temperature caused practically no decrease in modulus of elasticity (stiffness) or in modulus of rupture (bending strength), but the periods of one-half hour or longer caused a definite deficiency in shock resistance which increased progressively with prolongation of the heating period. The tests have also shown that heating in steam at 320° F. for 4 hours produces definite decreases in all strength properties and have demonstrated that heating in steam is more deleterious than heating between hot plates.

Veneer for use in plywood is in some instances made from logs that have been soaked for some hours in hot water to facilitate cutting and is often dried at temperatures of approximately 300° F. in order to expedite production. Temperatures up to about 320° F. are used subsequently in gluing plywood with thermosetting resins. Glued airplane parts are often subjected during assembly to temperatures well above the normal atmospheric value. Although these heating periods are ordinarily brief, the available data indicate that there may be some deleterious effect on strength properties. Furthermore, effects may be more pronounced on some species than on those on which tests have been made. Consequently it is desirable that in general temperatures applied in processing or preparing wood for use in aircraft should be kept as low and the aggregate duration of elevated temperatures as brief as possible. Subsequent to the original drying, elevated temperatures are ordinarily applied only to wood that is low in moisture content to which it is believed such temperatures are less harmful than to green or wet wood, although there is little specific information on this point.

There are few specific data on the strength of wood at temperatures other than the usual summer and winter room values (*5–8*). Wood at comparatively high moisture content is made weaker and more flexible when the temperature is raised and such information as is available indicates that it is made stronger and stiffer and possibly less shock-resistant when the temperature is lowered. It is probable that the temperature within the range to which aircraft is subjected has no large effect on the strength of wood in the normally dry state in which it is used.

5.063. Seasoning References.

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(5–2) Markwardt, L. J.
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5.1 CONTROL OF HUMIDITY IN FACTORIES

5.10. General In the construction of aircraft under assembly line production methods, dimensional changes in partly worked units mean waste of materials, loss of time, and upsetting of the production schedule; hence, dimensional stability of wood parts is important as a factor of production.

Since dimensional changes in wood are caused principally by changes in moisture content, it follows that conditions should be maintained in the wood shop that will prevent moisture changes. To minimize such changes, the moisture content of the wood at the time of manufacture should be as nearly as possible that which it would attain in service. The specifications establish limits of moisture content for wood parts at time of assembly at 5 to 7 percent for propellers and 8 to 12 percent for other parts. During World War I some data were collected by the Forest Products Laboratory on the moisture content of wood in Army and Navy airplanes (table 5–9).

Table 5–9.—*Moisture content of wood airplane parts under service conditions*

Kind of construction	Service	Stations where samples were taken [1]	Kinds of woods tested	Specimens tested	Moisture content		
					Average for specimens tested [2]	Maximum for any one station and wood	Minimum for any one station and wood
		Number	*Number*	*Number*	*Percent*	*Percent*	*Percent*
Solid and laminated wood [3]	Army	10	4	371	11.5	14.0	9.3
Propellers	do	9		75	10.3	11.3	8.4
Plywood	do	7		39	13.9	16.7	11.7
Solid and laminated wood [3]	Navy	10	10	419	12.7	15.3	8.8
Plywood	do	6	4	35	13.8	17.8	9.1

[1] Army and Navy stations are considered separately, although they are frequently located close to each other.

[2] Grand average for all stations where determinations were made; station averages were prorated on number of specimens tested.

[3] Exclusive of propellers.

Throughout a large part of the United States, the moisture content of wood stored or used out of doors and protected from rain averages about 12 percent. In the drier areas of the Southwestern States the average moisture content of wood is about 8 or 9 percent. Coastal zones in the Southeastern States, along the Gulf of Mexico, and in the Southwest average slightly higher than 12 percent, as do also tropical regions.

In most States, outdoor relative humidities during the summer are usually sufficiently high so that satisfactory equilibrium moisture content conditions can be maintained by adequate ventilation. However, when cool weather comes in the fall and buildings are heated, an important change takes place wherein lower humidities and equilibrium moisture content values are encountered. As the outside temperature decreases it can hold less and less water vapor per cubic foot than it could at higher temperatures, but when heated to normal temperatures, without changing its water content, this outside air has a greater capacity for moisture and since the relative humidity is the ratio of the quantity of moisture present in air to that which could be held at a given temperature, it is correspondingly lowered. This causes drying of materials stored or housed in heated buildings and workrooms. An illustration of the operation of this principle will be found by a study of table 5–10. In this table an average relative humidity of 75 percent for out-of-door conditions is assumed for illustrative purposes. It is also assumed that no water is added to the inside space. This latter assumption, although not strictly true where people are working and manufacturing operations are in progress, is nevertheless sufficiently accurate to show approximately how conditions inside a building may change as out-of-door conditions vary and why wood dries out during the winter in a heated building.

TABLE 5–10.—*Effect of outside temperatures on inside humidities and equilibrium moisture content values when the outside relative humidity is 75 percent*

Outside temperature	Corresponding inside conditions at 72° F.	
	Relative humidity	Equilibrium moisture content
°F.	*Percent*	*Percent*
70	70.1	13.0
65	59.0	10.6
60	49.5	9.0
55	41.3	7.7
50	34.4	6.7
45	28.5	5.8
40	23.5	5.0
35	19.3	4.3
30	15.6	3.6
25	12.4	2.9
20	9.8	2.5
15	7.7	1.9
10	6.0	1.5
5	4.6	1.1
0	3.6	(1)
−5	2.7	(1)
−10	2.1	(1)
−15	1.6	(1)
−20	1.2	(1)
−25	0.9	(1)

[1] Less than 1.1.

Some manufacturers of wood airplanes maintain a relative humidity of about 55 percent in the wood shop. This relative humidity keeps the wood at a moisture content of about 10 percent. Stock is brought into the shop from the kilns or storage rooms at or near this moisture content value and held in stickered stock piles for a week or more before being cut up. Since cold-gluing processes add moisture to the wood, the larger sized laminated parts are sent to a conditioning room after gluing (fig. 5–7) as discussed in section 5.28.

Figure 5–7.—Spars in conditioning room.

To prevent the moisture content of material being processed from becoming too low it is desirable to maintain a relative humidity of about 45 percent during the winter when inside humidities are otherwise likely to drop to very low levels. This condition would prevent moisture content values from falling below about 8 percent and would not introduce so serious a condensation problem as if a higher humidity were maintained. Condensation on windows and skylights may be minimized by double glazing, by heating the glass with steam coils, or by circulating warm air across the glass surfaces. Drip from condensing surfaces should be prevented wherever it is likely to damage materials being processed.

Preventive measures can be incorporated in new buildings at very little added expense. This is particularly true in the "blackout" type where no windows are used, as suitable vapor barriers in the side walls and ceilings are all that is needed. Where windows are used, they should be either double glazed or of the insulated block type.

Since humidification is not a requirement in the entire plant but primarily in the wood shop, it may be practical in buildings already erected to install protection for some or all of the vulnerable places as described.

5.11. Methods of Humidity Control. Where the storage of wood at a definite moisture content is desired, a room built inside a building, preferably with no exterior exposure and equipped with air-conditioning apparatus, makes an arrangement that can be used at any time during the year with satisfactory results. The apparatus and controls may be designed to meet the particular needs.

A definite moisture content in lumber awaiting use in storage buildings may also be maintained by controlling the temperature of the space within the building by means of a hygroscopic element attached to heaters. This can be done only so long as the prevailing relative humidities are high; they may be reduced by increasing the temperature of the space surrounding the lumber above that of outside temperatures. However, simple devices are available for humidifying so that moisture can be added if necessary.

For the conditioning of a large wood-using plant any one of several methods may be employed. A central plant may be designed to condition the air completely and may be equipped with refrigeration or absorption apparatus as well as heating and humidifying facilities. The air is distributed by means of a system of ducts throughout the building. Such equipment is expensive and probably not justified for most wood airplane factories.

Another method of accomplishing the same result as with the large central-station air-conditioning plant is to install a sufficient number of small air-conditioning units throughout the plant and use no distributing system. This method, if fully equipped for year-round control, is likewise expensive and perhaps nonessential in most cases.

As a rule, high humidities are not a problem in wood manufacturing plants in the northern part of the United States, and consequently conditioning equipment is needed only to increase the humidity during the heating season when low humidities prevail. On the other hand, in manufacturing plants situated in very damp climates, such as prevail along the Gulf Coast, dehumidification may be required.

To accomplish humidification, only relatively simple apparatus is needed. Steam jets may be distributed throughout the plant and may be controlled automatically by a moisture-sensitive instrument. The chief objection to the use of steam jets is that water is lost from the steam-generating plant and heat is added to the space. In winter this would probably not be objectionable, but it might be if humidification were required during a dry summer season. The simplicity of the steam jet system and the resultant freedom from dust residues commend it. Similar results can be obtained by the use of cold water and compressed air sprays. This is a very simple method by which water is discharged into the air by an air jet as a finely divided mist. The main objections to this method are a slight amount of noise, and—if the water used for evaporation contains minerals or organic material—a deposit of fine dust on materials in the room. Provision must be made to take care of drip from sprays of this kind. No heat, however, is added to the air from such sprays and a small amount of cooling results from the evaporation.

Target sprays are also a possibility for this purpose. They discharge a very fine stream of water against a plate. The bulk of the water striking the target is broken up into a fine mist which floats out into the room. Unless water free from minerals is used, fine dust is also scattered by this method. Adequate filters to prevent plugging of the fine openings and a drain to remove drip must be provided.

There are a number of mechanical devices on the market which have a rotating disk upon which water is allowed to flow. This disk rotates at high speed, so that the water is driven to the edge of the disk by centrifugal force and thrown against the edges of a series of sheet-metal vanes. The water is thus broken up into a fine mist and blown out into the room by a fan located behind the disk. This apparatus has disadvantages similar to those mentioned above. Residues resulting from evaporation of the water accumulate on the apparatus and form dust which floats about the room. Usually these evaporators are controlled by a hygroscopic element which opens or closes a water valve on the humidifier. A number of them could, however, be controlled from a single humidistat.

The control of the humidity near wood surfaces being heated is a problem which frequently concerns fabricators of airplane parts. This problem arises because of desirability of speeding up the setting of glues in order to make more frequent use of presses or jigs. Strip heaters, infrared lamps, tubes heated by steam, and warm air produce local conditions requiring attention.

When a wood surface is heated in the open the humidity of the space immediately adjacent to the surface is lowered and some drying is likely to occur—the higher the temperature, the lower the humidity, and the greater the moisture loss. Strip heaters, when tightly pressed against the wood surface, greatly retard the escape of moisture, and present no problem. Open surfaces heated with infrared lamps reach such high surface temperatures that humidification of the work room is of little value in preventing excessive surface drying. Under such conditions and when practical the heated area should be tightly covered with a thin layer of strip aluminum in order to prevent the escape of moisture and maintain as near the desired equilibrium condition at the surface of the wood as possible. The outer surface of the sheet metal should be painted a dull black in order that it receive and transmit as much heat as possible to the material behind it.

Where heat is applied by warm air, such as in a kiln or oven, the moisture content of the object being heated may be controlled by properly adjusting the relative humidity to that which would represent the equilibrium condition for desired moisture content. In certain cases it is advantageous to drop a canvas-covered frame over the work and to heat and humidify the limited space thus enclosed rather than the entire room.

Sling psychrometers and tables or curves for conversion of the measurements into relative humidity should be provided (sec. 5.012). Hair hygrometers or inexpensive humidity guides are unreliable unless they are carefully calibrated and checked from time to time. The equilibrium moisture content of wood, in prevailing atmospheric conditions, may also be determined by thin sections of wood exposed in the workrooms which can be weighed for determination of their moisture content. If a sample is designed to contain 100 grams when oven dry, the number of grams over 100 will be numerically equivalent to the percentage of moisture in the sample. In preparing such a sample, select air-seasoned material of known moisture content and work it down until its weight in grams is equal to 100, plus a number of grams equal to the percentage of moisture. For example, a sample containing 10 percent moisture content should weigh 110 grams, of which 100 grams is dry wood substance and 10 grams is moisture. Such samples should not be oven dried.

5.2. GLUING.

Satisfactory glue joints in aircraft develop the full strength of the wood under all conditions of stress. To produce this result, the conditions involved in the gluing operation must be carefully controlled so as to obtain a continuous, thin, uniform film of solid glue in the joint with adequate adhesion to both surfaces of the wood. These conditions involve:

1. Proper moisture content of the wood.
2. Properly prepared wood surfaces.
3. Glue of good quality, properly prepared.
4. Good gluing technique.

A satisfactory joint and two types of unsatisfactory joints, resulting from improperly controlled gluing conditions, are shown in figure 5–8.

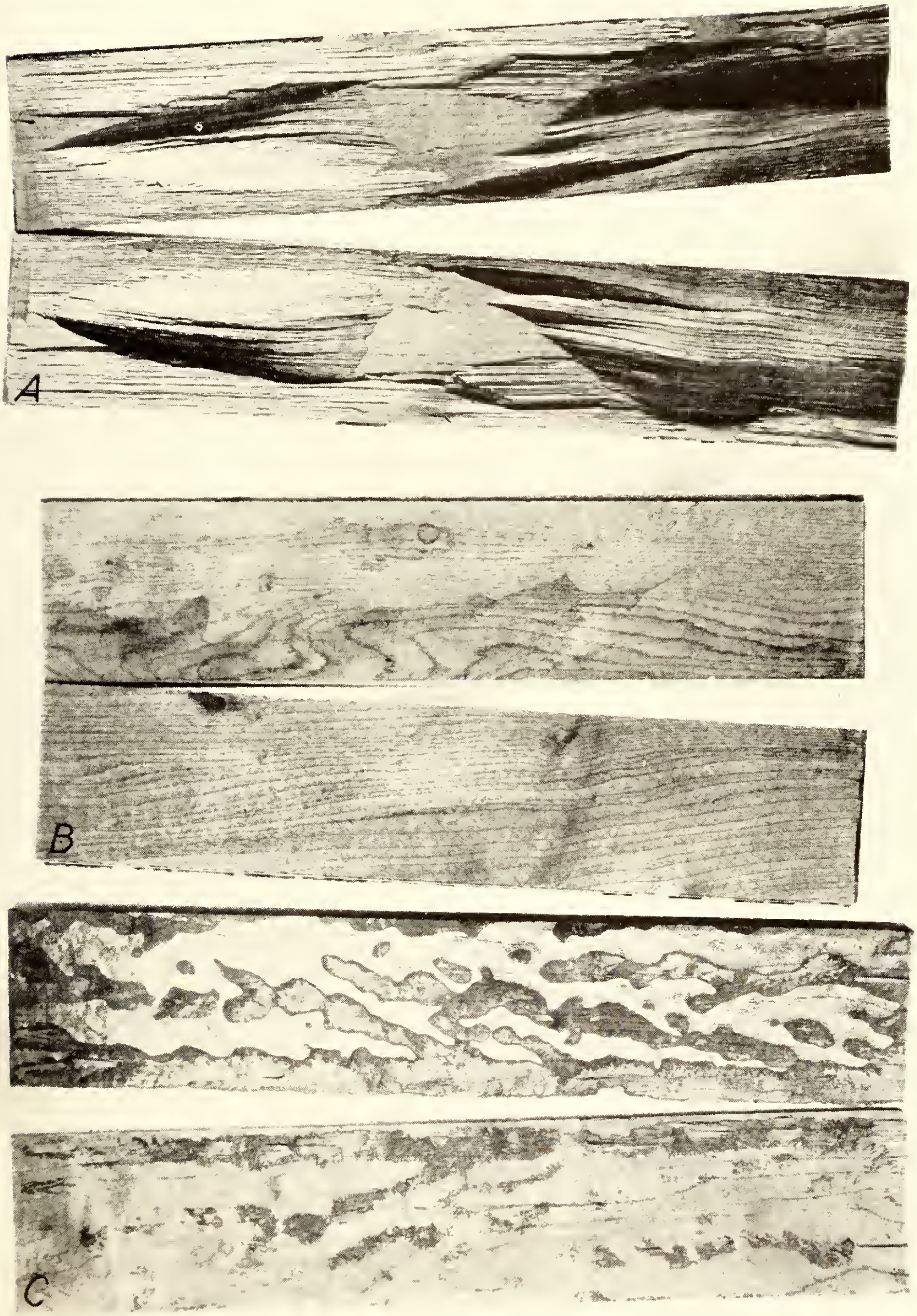

Figure 5-8.—Strong and weak joints resulting from different gluing conditions. *A*, well-glued joint with a high percentage of wood failure made under proper gluing conditions; *B*, starved joint, which results from the application of excessive pressure with thin glues: *C*, dried joint, resulting from too long an assembly period or insufficient pressure.

5.20. Moisture Content for Gluing. The drying and conditioning of wood to the proper moisture content for aircraft use are described in sections 5.03 and 5.04. The moisture content of the wood affects the results obtained in gluing and, in turn, is affected by the gluing process. It may be either increased or decreased, depending on (1) the gluing process used, (2) the form and composition of glue, (3) the amount of glue spread, and (4) the dimensions of the wood parts glued. In general, hot-press methods reduce the moisture content and cold-press processes increase it. Glues of high water content add more moisture to the wood than glues of low water content, and heavy spreads add more than light spreads. More water is added by the glue to a construction made of thin plies than to one made of thick plies. The percentage increase in moisture content from a given amount of glue spread will be greater in woods of low specific gravity than in woods of high specific gravity.

Table 5–11 illustrates approximate percentages of moisture added to wood in cold-pressing operations for certain types of aircraft members. Most hot-pressing operations, however, reduce rather than increase the moisture content of the wood in gluing. The moisture content of panels, when removed from hot presses, is normally well below the 8- to 12-percent range that is required for aircraft plywood (Specifications AN–NN–P–511b and AN–P–43), and the manufacturers of the plywood must introduce moisture into the panels by a conditioning process in order to bring them within the required range (sec. 5.28). The moisture content of veneer normally shows little or no change during bag-molding processes of making plywood (sec. 5.341).

TABLE 5–11.—*Calculated percentages*[1] *of moisture added to wood in gluing with cold-press glues*

Construction		Moisture added in gluing[2] with	
Number of plies or laminations	Species and thicknesses of plies or laminations	Cold-setting resin glues	Casein glues
		Percent	*Percent*
2	1/28-inch yellow birch plies	8.1	21.9
3	1/32-inch yellowpoplar faces 1/20-inch yellowpoplar core	15.9	42.7
5	1/16-inch mahogany faces		
	1/12-inch mahogany cross bands	9.4	25.2
	1/24-inch mahogany core		
7	All laminations—1/8-inch Sitka spruce	6.0	16.5
11	All plies—1/10-inch black walnut	6.0	16.1
6	All laminations—3/8-inch Sitka spruce	2.0	5.3
3	All laminations—3/4-inch Sitka spruce	.8	2.1
10	All laminations—3/4-inch yellow birch	.7	1.9
2	3/32-inch yellowpoplar plywood and 3/8-inch thick Sitka spruce	1.9	5.1
2	1/8-inch yellow birch plywood and 2-inch thick Sitka spruce	.4	1.1

[1] Calculated percentages are based on oven-dry weight of woods. In the calculations it is assumed that all the surplus moisture added by the glue is absorbed by the wood. This assumption is known to be somewhat in error, but it nevertheless affords a satisfactory basis for comparison.

[2] Spreads of 75 pounds of wet casein and 47 pounds of wet cold-setting, urea-resin glue per 1,000 square feet of single glue line are assumed in these calculations. It is assumed that the cold-setting resin glue is mixed 1 part dry glue and 0.65 part of water, and the casein glue 1 part dry glue and 2 parts water.

Changes in moisture content of the wood after the glue has set develop stresses in the glue line and reduce the load that the member will withstand in service. To minimize the stresses in a glued structure which develop from moisture content changes, the member should have a moisture content, when the glue sets, that is approximately equal to its average moisture content in service. Moisture content determinations on wood aircraft parts have been made at the following locations in the United States: New York, N. Y.; Garden City, N. Y.; Quantico, Va.; Philadelphia, Pa.; Anacostia, D. C.; Hampton Roads, Va.; Aberdeen, Md.; Washington, D. C.; Cleveland, Ohio; Fairfield, Ohio; Dayton, Ohio; Pensacola, Fla.; Little Rock, Ark.; San Antonio, Tex.; Tucson, Ariz.; San Diego, Calif.; Santa Monica, Calif.; Sacramento, Calif.; San Francisco, Calif.; and Seattle, Wash. There was considerable variation in moisture content of similar wood aircraft parts at the same station during different seasons and among stations. The moisture content relationships at different stations during the same season or at a single station during different seasons were found to be in equilibrium with the relative humidity relationships given in table 5–1. The lowest moisture content values were found in wood parts sampled at Tucson during early summer and the highest at coastal stations during winter. The moisture content of solid and laminated wood parts varied from 5.8 to 15.3 percent, of plywood from 5.9 to 17.8 percent, and of propellers from 8.4 to 10.3 percent. No moisture content measurements, however, were made on propellers at Tucson.

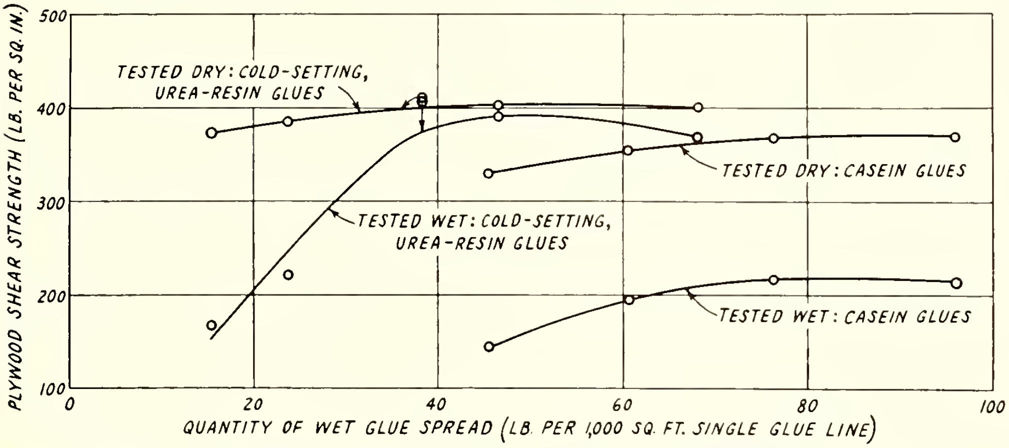

Figure 5-9.—Effect of moisture content of veneer on shear strength of plywood joints for cold-setting glues.

Moisture content measurements on wood in dwellings and on spruce test panels, exposed at several stations in the arid Southwest, indicate that the moisture content of wood often drops to about 6 percent during the spring and summer (*5–11*, *5–14*). From all available information it appears that the normal moisture content of different wood parts of aircraft in service in the continental United States may range from as low as 6 to as high as 18 percent.

The effect of moisture content of veneer at the time of gluing on the strength of joints in plywood glued with cold-setting, synthetic-resin and casein glues is illustrated in figure 5–9. The veneer used was $\frac{1}{16}$-inch birch and sweetgum and glued into 3-ply panels. The gluing pressures were from 150 to 200 pounds per square inch and the assembly times from 3 to 12 minutes. The dry-strength tests were made on the plywood at 6 to 12 percent moisture content and the wet-strength tests were made immediately after the specimens were soaked in water at room temperatures for 48 hours.

It may be noted that a range in moisture content of the wood between about 7 and 12 percent gave maximum strengths, when tested both dry and wet, for both the cold-setting resin and casein glues. Since ply thicknesses, species, glues, and gluing processes affect the percentage of moisture added to the wood, the optimum moisture content for maximum strengths varies somewhat with different structures and processes. Considering all factors, however, it is recommended that, in cold-press gluing, veneers and thin laminations up to ⅛ inch in thickness have at the time of gluing a moisture content of 5 to 8 percent, and that stock thicker than ⅛ inch have from 8 to about 12 percent. For hot-press gluing, using aqueous suspensions of resins on thin plies, a moisture content of 5 to 8 percent is applicable and for dry film and nonaqueous resin glues, or for aqueous glues on thick plies, the moisture content should range between 8 and 12 percent.

5.21. Machining Wood for Gluing. Wood should be machined for gluing only after it has been uniformly conditioned to the desired moisture content. Drying and conditioning stock after it has been machined produce distortion and surface irregularities, which are objectionable from a gluing standpoint. It is recommended that no more than 8 hours be permitted to elapse between final surfacing and gluing. Specification AN–P–15a requires a lapse not to exceed 4 hours between surfacing and gluing. The gluing surfaces should be machined smooth and true. Planer marks, chipped or loosened grain, and other surface irregularities should not be permitted.

5.210. Methods. With normal wood, smooth, even surfaces produced on planers and jointers with sharp knives and correct feed adjustment are best for gluing. Surfaces that are satisfactory for gluing can be produced with special types of saws, but the operation must be carefully controlled. Satisfactory sawn surfaces should approach well-planed surfaces in uniformity, smoothness, and freedom from crushed fibers. Glue joints made on surfaces that are covered with crushed fibers do not develop the normal full strength of the wood. When glue joints that have been made on surfaces covered with crushed fibers are broken, they usually show a thin but complete coverage of wood fibers on the glue line. These abnormal and undesirable wood failures are the result of crushing and weakening of the surface layers of fibers by poor machining technique. Crushing can be detected by examining the sawn or planed surfaces with a hand lens that magnifies about 10 times and comparing them with surfaces prepared by splitting. On undamaged wood surfaces, the outline of the wood elements is quite distinct, whereas on crushed wood surfaces the elements are indistinct and distorted.

5.211. Machining Joints. The machining of joints of irregular shapes, such as the tongue-and-groove, for the purpose of presenting larger gluing areas is not usually advisable. Irregularly shaped surfaces are more difficult to machine for perfect fitting of parts than are plain, straight surfaces. Lack of contact may make the effective holding area smaller in the shaped joint than in a straight, flat joint, and this may actually reduce the strength. Furthermore, if proper gluing practices are used, planed side-grain surfaces of the woods used in aircraft can be glued in such a manner as to develop the full strength of the wood (sec. 5.27) and the extra contact surface becomes superfluous as far as strength is concerned.

The faces of well-manufactured veneer are suitable for gluing without further machining or preparation (sec. 2.320) but, where two or more pieces of veneer are joined at the edges to form a larger piece or assembly, the edges must be jointed straight and square. This is usually accomplished satisfactorily on regular veneer jointers.

5.212. Surface Treatments. Sanding, tooth planing, or other means of roughening smooth, well-planed surfaces of normal wood before gluing are not recommended. Such treatment of well-planed wood surfaces may result in local irregularities and objectionable rounding of edges. While sanding of planed, normal wood surfaces is not recommended, sanding is a valuable aid in improving the gluing characteristics of some plywood surfaces; wood that has been compressed through exposure to high pressures and temperatures; resin-impregnated wood (impreg and compreg) (sec. 5.272); and laminated paper plastic (papreg) (sec. 3.5). Sanding also finds useful application in cutting scarf joints on thin veneers and plywood (sec. 5.63) and in floating or contouring the surfaces of certain assemblies (sec. 5.658).

Wood surfaces for gluing should be free from oil, finishing materials, dust, dirt, old glue, crayon marks, and other extraneous materials. Where sizing of joint surfaces is practiced, care must be taken that the size does not interfere with the adhesion of the glue. In such cases it is safest to prepare the size by diluting the glue that will be used to make the joints (sec. 5.271).

Wood surfaces that are "glazed" from dull tools or by being pressed excessively against smooth, hard surfaces are somewhat more difficult to glue than normal wood surfaces. Glazing results from crushing or compression of the surface fibers so that they appear glossy. The gluing of glazed surfaces can be improved by preliminary treatments. A light sanding to remove the crushed fibers, or the application of water, which tends to restore the surface fibers to their original condition, is helpful.

Plywood surfaces may present more difficult gluing problems than do freshly planed wood surfaces. During the manufacture of plywood, unfavorable surface conditions occasionally develop that interfere with adhesion of glue in secondary gluing operations. Some of the surface changes that occur in plywood manufacture and that may interfere with the adhesion of glue in secondary gluing, such as glazing and heavy "bleed-through" of glue, are readily recognized. In contrast to these readily recognized surface conditions, wax deposits from cauls during hot-pressing produce unfavorable gluing surfaces that are not easily detected.

In addition to these unfavorable surface conditions of plywood, the causes of which are known, there are others for which the causes have not yet been established. Wetting tests are useful as a means of detecting the presence of wax. Drops of water placed on the surface of wax coated plywood do not spread or wet the wood. Wetting tests may give some indication of the presence of other unfavorable conditions, but they cannot be relied upon completely to evaluate the gluing properties and, at present, preliminary gluing tests appear to be the only positive means of actually determining the gluing characteristics of plywood surfaces.

Many of these unfavorable surface conditions of plywood can be avoided by changes in manufacturing practices. Glazing frequently results when plywood is hot pressed at high temperatures and pressures between metal platens, metal cauls, or hard, compressed wood cauls. The manufacturer of the plywood can conveniently remove much of the glaze by properly processing or conditioning the panels after removal from the hot press. Since plywood from the hot press is abnormally dry, the addition of moisture is necessary to bring it within the required moisture content range for aircraft use. By applying the proper amount of water to the faces and then stacking the panels solidly for equalization, the plywood is brought to the proper moisture content, and at the same time the glaze of the faces is largely removed. The moisture may be conveniently applied by passing the panels between water-covered rolls such as those in a glue spreader, by spraying, or by a short period of exposure to a high humidity (sec. 5.281).

Bleed-through of glue is most often encountered on thin-faced plywood, and is usually but not entirely limited to hardwoods such as birch and mahogany. The porous nature of these woods permits the flow of the glue from the joint to the faces during hot pressing. Bleed-through is commonly associated with too high moisture content of the veneer at the time of gluing. Although it is difficult to eliminate bleed-through of glue completely on thin-faced plywood, it can be greatly minimized by careful control of moisture content of veneers before hot pressing.

The presence of even small quantities of wax on the faces of plywood greatly interferes with adhesion of glues in secondary gluing Such wax deposits usually result from the use of waxed metal or wood cauls during hot pressing, and can be easily avoided.

These unfavorable surface conditions of plywood can usually be corrected and their effects minimized by lightly sanding the surfaces with No. 3–0 or 4–0 garnet paper before gluing. Removing as little as 0.001 inch from the surface appears to be just as effective as heavier sanding in correcting the gluing characteristics of plywood otherwise difficult to glue (*5–13*). The danger of over-sanding and resultant impairment of the strength of the plywood can be minimized by specifying the use of sandpaper no coarser than No. 3–0 garnet on species of high density and no coarser than No. 4–0 on species of low density. Frequent thickness measurements are advisable when sanding is practiced. In no case should thickness reductions exceed 10 percent of the face-ply thickness.

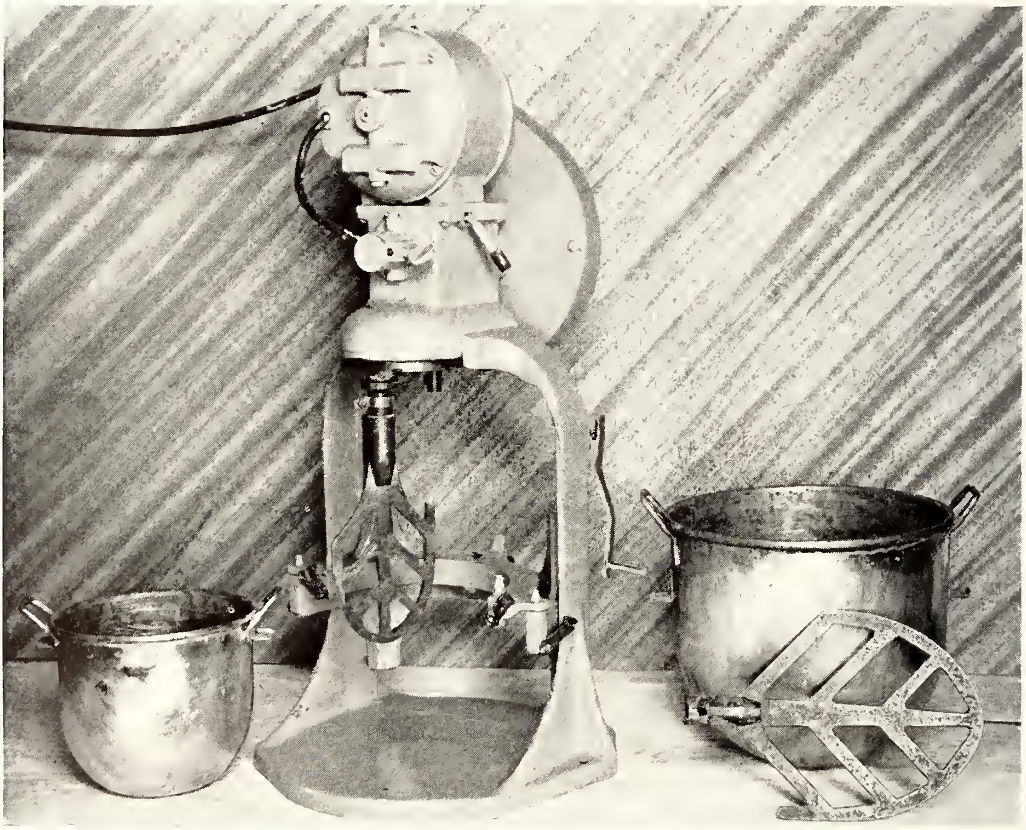

FIGURE 5-10—Three-speed, dough-type, electric mixer equipped with 3- and 8-quart bowls and two sizes of paddles for mixing glues.

5.22. Preparation of Glues for Use. The dry-film types of glue are bought ready for use. Manufacturers' directions should be followed for the preparation of other glues. Clean, cool water should be used when mixing glues unless warm water is specified by the glue manufacturer. The proportions of dry glue and water or other solvent should be determined by weight rather than by measure or guess. The correct proportion of glue and water varies with the particular brand of glue and somewhat with the type of joint. Manufacturers usually recommend the proportions of glue and water, and these should be followed unless other proportions are known to give better results. Alcohol and alcohol-water mixtures are used as solvents for many of the phenol-formaldehyde glues.

The mixed glue should be free from air bubbles, foam, and lumps of undissolved material. Machine stirring normally produces a more thoroughly mixed glue than hand stirring but small batches of one-half pound or less of dry glue may be prepared satisfactorily by hand stirring. The dry resin glues are quite easily mixed with water; the casein glues normally require a longer mixing period and more stirring. Various types of mixers have been used successfully, but the dough type, figure 5–10, equipped with a mechanism for turning the paddle in a double-rotary motion at two or three different speeds, has been quite generally used with excellent results for both casein and resin glues.

The chief requisites of a mixer for casein and synthetic-resin glues are (1) thorough but not violent agitation, preferably with different speeds of the paddle, and (2) a bowl that can be readily removed from the machine for cleaning and made of some metal that will not corrode rapidly from the action of acid or alkali. Bowls and paddles of copper and brass are unsuitable.

Mixers, spreaders, and other equipment used with all glues should be thoroughly cleaned at regular intervals. A thorough cleaning every working day, before the glue hardens, is highly desirable.

5.220. Resin Glues. Liquid resin glues may come ready for use or in a form which requires only the addition of a hardener. Cold-setting, liquid-resin glues are usually sold with the hardener in a separate container, in which case the hardener and the resin must be thoroughly mixed together before use. All liquid-resin glues and liquid hardeners should be thoroughly stirred before use to assure uniformity, inasmuch as any filler or other materials added during manufacture may settle out during shipment.

A number of the resin glues are sold in powder form. Since some segregation of the dry materials may occur during shipment, it is advisable to mix the contents of each container thoroughly before combining with the solvent. Hardeners for some of the dry resin glues are shipped separately and combined with the resin at the time of mixing with water.

Probably the most generally applicable procedure for mixing cold-setting, urea-resin glues that are delivered in powder form is to place about two-thirds of the required water in the mixing bowl, add the powder slowly with constant stirring, allow the mass to mix until smooth and free from lumps, and then add the remainder of the water. Continue the stirring for a few minutes thereafter until the mixture is of uniform consistency throughout. Variations in procedure are advisable for certain prepared glues of both liquid and powdered forms, and in such glues the glue-water proportions and other details should be supplied by the manufacturer.

Cold-setting, synthetic-resin glues, when prepared for use, are usually sharply limited in working life and care should be taken to discard the glue and clean the equipment before the end of the working-life period. Satisfactory joints can be made as long as the glue can be spread satisfactorily but, if the glue sets in any spreading or mixing equipment, the cleaning will be a difficult operation. In very warm weather it may be found advisable to keep the glue pot in a bath of cool water, approximately 70° F., to prolong the working life of the mixture.

5.221. Casein Glues. For most prepared casein glues, a ratio of 1 part of glue to 1.75 to 2 parts of water (by weight) gives a proper consistency for side-grain joints. For gluing end-grain joints, some variation in the glue-water ratio is necessary as described in section 5.271. The dry powder is mixed thoroughly with the water and stirred until it has dissolved. The water should first be placed in the bowl of the mixer and the glue sprinkled or sifted in slowly, with the paddle in motion. Care should be used that large lumps do not form.

For most commercial casein glues it is recommended that mixing be continued only for 3 to 5 minutes after the powder is added to the water. The glues are then allowed to stand without agitation for 15 to 30 minutes and again mixed for 3 to 5 minutes before using. Many of the casein glues thicken and set to stiff pastes during or soon after the original mixing but return to workable consistencies during the rest period. This original thickening is normal for these glues and not an indication that too little water was used. Most commercial caseins have working lives, at

70° to 75° F., of at least 5 hours, but they thicken noticeably towards the end of this period. The quality of joints, however, is unaffected as long as the glues can be applied satisfactorily. Casein glues used for aircraft assembly must set to stiff gels at some time after the specified working life.

5.23. Spreading of Glue. To make a satisfactory joint, it is necessary to spread evenly the amount of glue needed, and for certain classes of work this should be done within as short a time as possible. These requirements can often be most easily met by machine spreading, but in the construction of aircraft parts from many small and irregularly shaped pieces it is frequently necessary to spread by hand. Thick glues are difficult to spread by hand, and it is therefore best to use a machine spreader for them whenever possible (fig. 5–11).

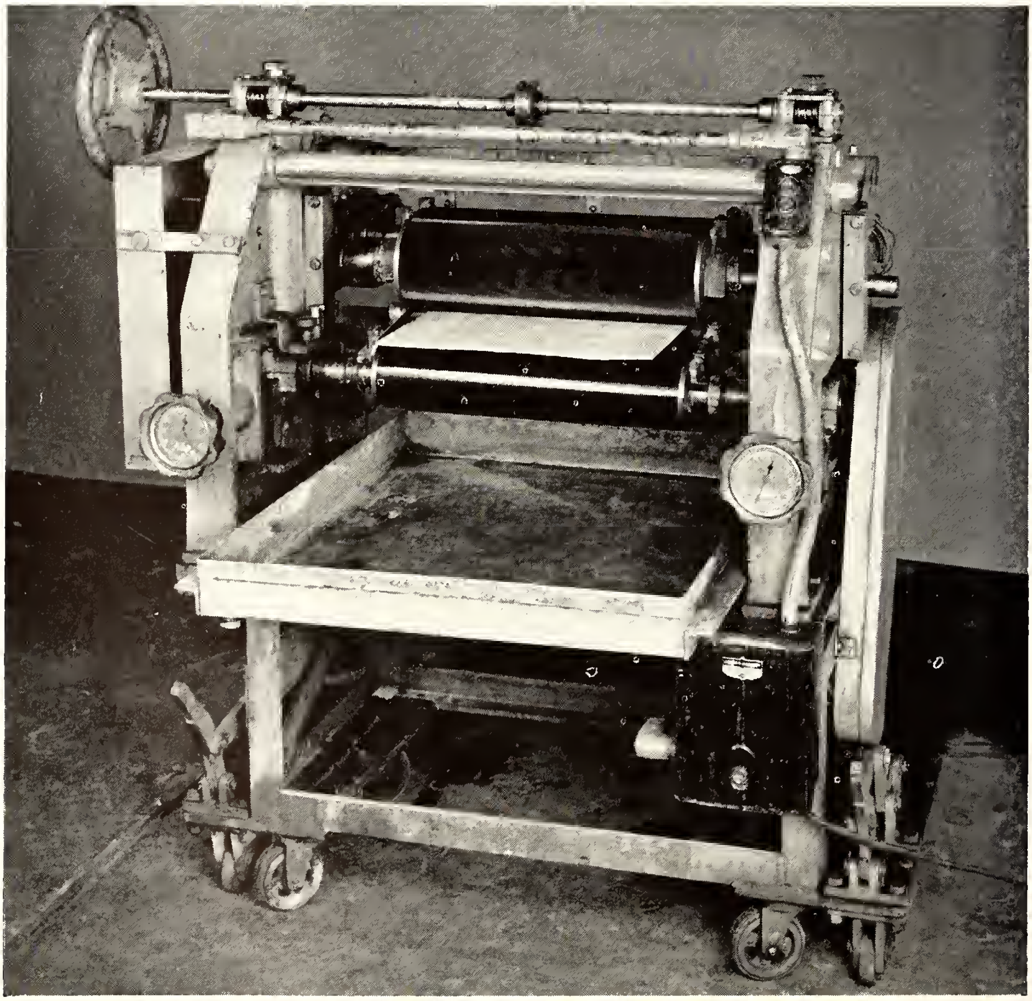

FIGURE 5–11.—Typical glue spreader with rubber-covered rolls used for spreading resin glues.

Within certain limits, the strength of glue joints increases with the quantity of glue spread. This is illustrated in figure 5–12. These data are from plywood glued with cold-setting, urea-resin, and casein glues under good gluing conditions and tested in the regular plywood-joint test (sec. 4.3). In other tests it has been found that, with less favorable gluing conditions, the quantities required to produce maximum strength of joints are usually increased slightly over those indicated in figure 5-12. The same general relationship holds for other wet-glue mixtures, although the optimum amount of spread and the rate of change in the strength of joints may vary somewhat.

For most aircraft gluing operations in which glue is spread on but one of the two contact surfaces, the following spreads of wet-glue mixtures are recommended:

Glues	*Pounds per 1,000 square feet single glue line*
Cold-setting urea resins	45 to 50
Casein	65 to 75
Hot-press urea and phenolic resins	45 to 50

The above recommendations are equivalent to about 22 to 30 pounds of dry glue per 1,000 square feet of single glue line. It is desirable to use the maximum amounts recommended for each type of glue, and even to increase them if the wood surfaces are rough, end or sloping grain is exposed on the contact surfaces, or assembly times exceed the recommended limits.

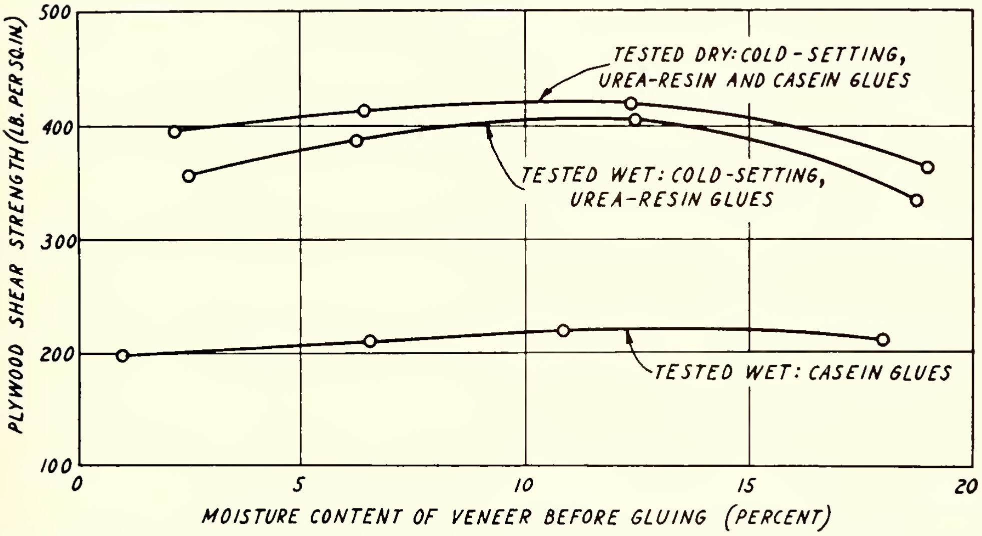

FIGURE 5-12.—Relation between quantity of glue spread and plywood joint strength. Tests made on 3-ply panels of hardwood veneer, glued with cold-setting, urea-resin, and casein glues. Veneer between 7 and 12 percent moisture content; gluing pressures 150 to 200 pounds per square inch; assembly times 1 to 19 minutes; number of specimens 50 to 100 for each test point.

Under certain conditions of gluing such as long assembly periods, rough wood surfaces, scarf joint surfaces, or excessively sloping or end-grain surfaces, double spreading should be used. When both contact surfaces are spread with glue, the total amount applied should be approximately 25 percent more than is recommended for single spreading. Under favorable gluing conditions, the glue need be spread on but one of the two contact surfaces (single spreading). Tests on both plywood and laminated constructions indicate that no significant difference in strength of joints results from single or double spreading if other conditions are satisfactory.

The weight of dry film glues, of which approximately two-thirds is glue and one-third is paper, is about 12 to 13 pounds per 1,000 square feet. On roughly cut and thick veneers the use of two sheets of the film per joint improves the quality of the bonds.

5.24. Assembly Time in Gluing. Where pieces of wood are coated and exposed freely to the air, a much more rapid change in consistency of the glue occurs than where the pieces are laid together as soon as the spreading (single or double) has been done. The condition of free exposure is conveniently referred to as "open assembly," and the other as "closed assembly."

The effect of assembly time on the strength of casein and cold-pressed urea-resin glue joints under closed assembly conditions is illustrated in figure 5–13. The tests were made on plywood, glued with three plies of $\frac{1}{16}$-inch hardwood veneer of 6 to 12 percent moisture content, under 200 pounds of pressure per square inch, and at a room temperature of approximately 75° F. The dry strength tests were made on the plywood at 6 to 12 percent moisture content and the wet strength tests immediately after soaking the specimens in water at room temperatures for 48 hours. The plywood was tested by the regular plywood-joint test (sec. 4.3). Maximum dry and wet strengths of cold-setting, urea-resin glue joints, and the dry strengths of casein-glue joints were obtained at assembly times between about 5 and 12 minutes. Other test data indicate that, with lower gluing pressures and higher room temperatures, other conditions remaining unchanged, the decrease in strength with assembly periods longer than 12 minutes is somewhat more rapid, but that the decrease with the shortest assembly times is even less than shown in figure 5–13. The production of maximum wet strengths with casein glues at the somewhat longer assembly periods is believed to be related to the amount of moisture added to the plywood in gluing (table 5–11), the development of stresses while the plywood is drying, and the subsequent release of these stresses during the soaking period prior to testing.

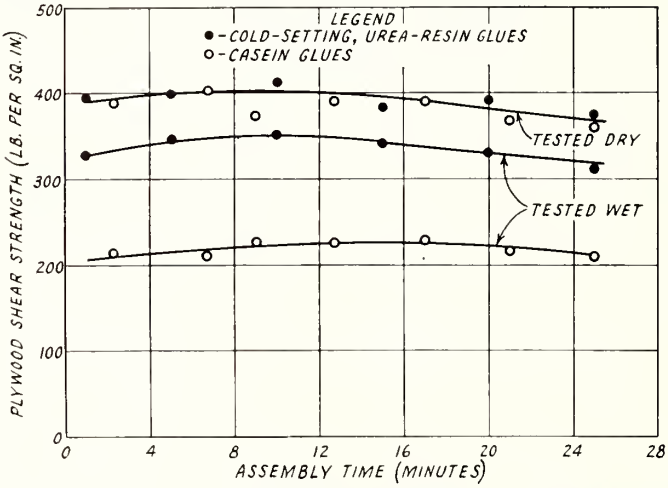

FIGURE 5–13.—Effect of closed assembly time on shear strength of plywood joints. The number of specimens tested for each assembly time ranged from 40 to 110.

Where the cold-setting glues are coated on wood parts and left exposed to the atmosphere (open assembly) the allowable assembly time is reduced by approximately one-half, as compared with closed assembly periods. In table 5–12 are given approximate ranges in assembly times, which are recommended as a guide in using cold-setting glues under open and closed assemblies, and for given ranges of temperature and gluing pressure.

Since most gluing operations involve both open and closed assembly, the allowable interval between the start of spreading and the time final pressure is reached will usually fall between the limits for closed and open assembly (table 5–12). The allowable limits for any operation can be estimated from the general relationship that one minute of open assembly is equivalent to two minutes of closed assembly.

Permissible assembly times vary greatly for hot-press glues of different types and specific formulations, with maximum allowable limits ranging from approximately 20 minutes to many days. Manufacturers' instructions should be followed, if reliable shop experience or test data are not available, for any specific adhesive. Table 4–1, however, shows estimated assembly life for a number of commercial brands of glues.

5.25. Use of Pressure. The application of adequate and well-distributed gluing pressure is one of the most important factors in producing consistently good joints. Pressure on the joint during the early stages of setting is required for best results in practically all types and forms of gluing. The functions of pressure include spreading of the glue to form a continuous film between the wood layers, forcing air from the joint, bringing the wood surfaces into intimate contact with the glue, and holding them in this position while the glue sets.

TABLE 5–12.—*Range in recommended assembly time for cold-setting glues* [1]

Kind of glue	Temperature of room and wood	Gluing pressures	Manner of assembly	Allowable assembly time
	°F.	*Lb. per sq. in.*		*Minutes*
Cold-setting urea resins	70–90	100 to 200	Closed	Up to 20
Do	70–90	100 to 200	Open	Up to 10
Do	70–90	75 and less	Closed	Up to 15
Do	70–90	75 and less	Open	Up to 8
Casein	70–90	100 to 200	Closed	Up to 20
Do	70–90	100 to 200	Open	Up to 10
Do	70–90	75 and less	Closed	Up to 15
Do	70–90	75 and less	Open	Up to 8

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[1] The recommended assembly times for the conditions specified are applicable for glues which meet current specifications; though it is recognized that some specific brands and formulations will permit somewhat longer assembly times than those recommended herein; also, it is assumed that customary mixtures of the glues and recommended spreads will be used. When double spreading is practiced the permissible assembly periods may be increased by 25 percent.

The best results in gluing are obtained when the pressure is distributed uniformly over the entire joint area. Fluid pressure, such as is used in bag-molding processes with thin veneers, most nearly accomplishes this result. The application of similar amounts of pressure at numerous and regularly spaced points over the joint area, as in nail-gluing, approaches this condition, but with thin layers the pressures at and between the points of application may still vary considerably. Cauls, blocks, and strips are frequently used between the pressure members and the layers being glued, to distribute the load from the point of contact to other parts not directly under the load. This is particularly necessary where thin layers are glued and the points of pressure application are some distance apart. Obviously, such pressure distributing members must be true and even or they do not fulfill their purpose.

Nonuniform gluing pressure commonly results in weak and strong areas in the same joint. The principal causes of unequal pressure on joints are: (1) irregular surfaces of the pieces being glued, (2) unequal dimensions of stock, (3) warped stock, (4) improper spacing of the pressure-bearing members, and (5) deformation, deflection, and other imperfections in press, clamps, or other pressing equipment.

5.250. Amount of Pressure. The amount of pressure required to produce strong joints varies over a wide range. This is illustrated by the application of pressure by such methods as nail gluing, where the pressures obtained are usually low, and at the other extreme the use of jack screws and hydraulic presses, by means of which very high pressures may be obtained. The range of pressures involved in aircraft assembly operations may vary from about 10 to 250 pounds per square inch. Species of high crushing strength require and withstand higher gluing pressures than woods of low strength. The successful use of light pressures presupposes that the wood surfaces are true and accurate as to fit or that they deform readily under small loads. The minimum pressure permissible for any assembly is one that will insure close contact of the wood surfaces and hold the members in close contact until the glue has set. Insufficient pressure and poorly machined wood surfaces usually result in the production of thick glue lines, which are objectionable and should be carefully guarded against. The pressure necessary to insure close contact between surfaces depends on the viscosity of the glue and the thickness or stiffness of the members.

It is very difficult to measure the viscosity of a glue mixture after it is spread on wood surfaces. At the time of pressing, however, a glue of the proper consistency will flow sufficiently under the gluing pressure to show a line of glue at the joint edge. The absence of "squeeze-out" at the joint edge usually indicates a dried joint (fig. 5–8, *C*). If, on the other hand, there is excessive glue flow from the joints, and spreads have not been heavy, starved joints may result (fig. 5–8, *B*). The resin film glues constitute an exception to these general considerations. The resin film glues undoubtedly flow within the joints but rarely show a line of squeeze-out at the edges. The absence of squeeze-out with the film glues is probably accounted for by the small amount of glue present (sec. 5.23).

In addition to the viscosity of the glue at the time of pressing, the pressure required to bring the wood surfaces into intimate contact and the crushing strength of the species affect the amount of gluing pressure that should be applied. Recommended pressures for gluing thick laminations or for gluing between metal platens, thick cauls, and other rigid surfaces are substantially higher than where fluid pressure or thin members are used.

Recommended pressures for specific aircraft gluing operations are given in section 5.4.

5.251. Methods of Applying Pressure. The methods employed in applying pressure to joints in aircraft gluing operations range from the insertion of brads, nails, and screws to the use of hydraulic and electric power presses. Most flat aircraft plywood is glued on power presses equipped with gages, so that the amount of pressure applied can be accurately determined and controlled (fig. 5–14). Likewise, in fluid-pressure operations the amount of pressure can be controlled. The amount of pressure applied by hand devices, however, is not so readily determined.

In figure 5–15 are illustrated some of the more common means of applying pressure to glue joints by hand. Nail gluing (fig. 5–15, *A*) is still used rather extensively in the gluing of ribs and in the application of plywood skins to the wing, control surfaces, and fuselage frames, although it is being replaced with pressure jigs designed for specific parts and operations (sec. 5.4). The spring clamp (fig. 5–15, *B*) has been used for the gluing of small, narrow joints and the eccentric clamp when gluing reinforcing blocks in place. Wood clamps and C-clamps (fig. 5–15, *D* and *E*) are extensively used to glue spars, spar flanges, reinforcing blocks, and bow ends. The larger laminated members, such as spars and propellers, are usually pressed under jackscrews (fig. 5–15, *F*) mounted on frames, where several are used on the same joint. The bar clamp (fig. 5–15, *G*) is useful when gluing pieces edge to edge.

The amount of pressure that can be applied with the different devices illustrated in figure 5–15 varies greatly. The amount applied by a single brad may be only a matter of pounds, whereas several tons can be applied by jackscrews. The spring

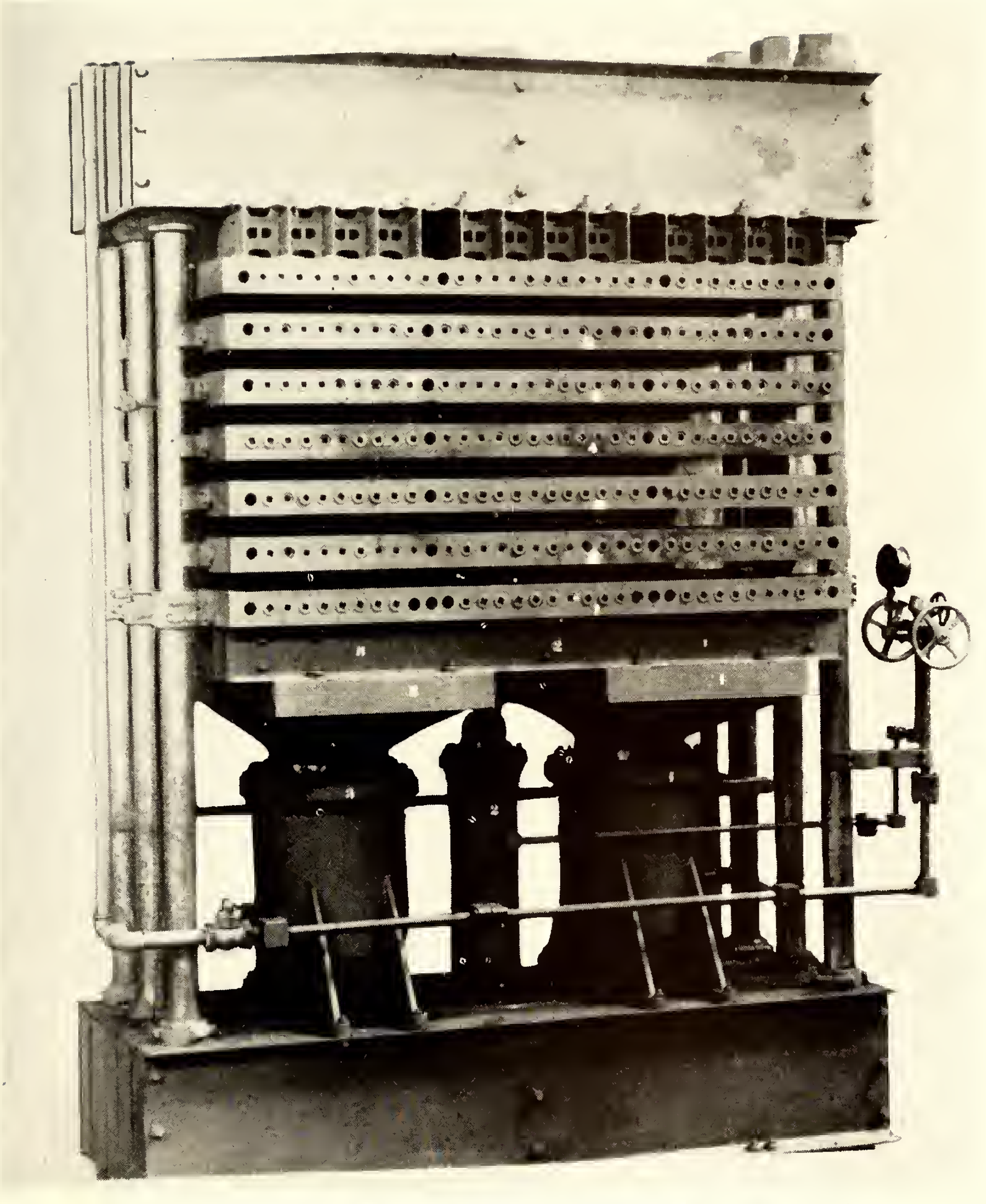


FIGURE 5-14.—Hydraulic, 6-opening, hot-plate press used in the manufacture of flat plywood.

and eccentric types of clamps of the usual sizes likewise are limited to relatively small loads. Calculations of the approximate amounts of pressure applied by them may be made, since the load and force applied are related to the distances from the fulcrum of the clamp to the points of application. Tests made on devices *D*, *E*, *F*, and *G* of figure 5-15 have provided the data shown in table 5-13, which may serve as a guide in the use of similar pressure equipment.

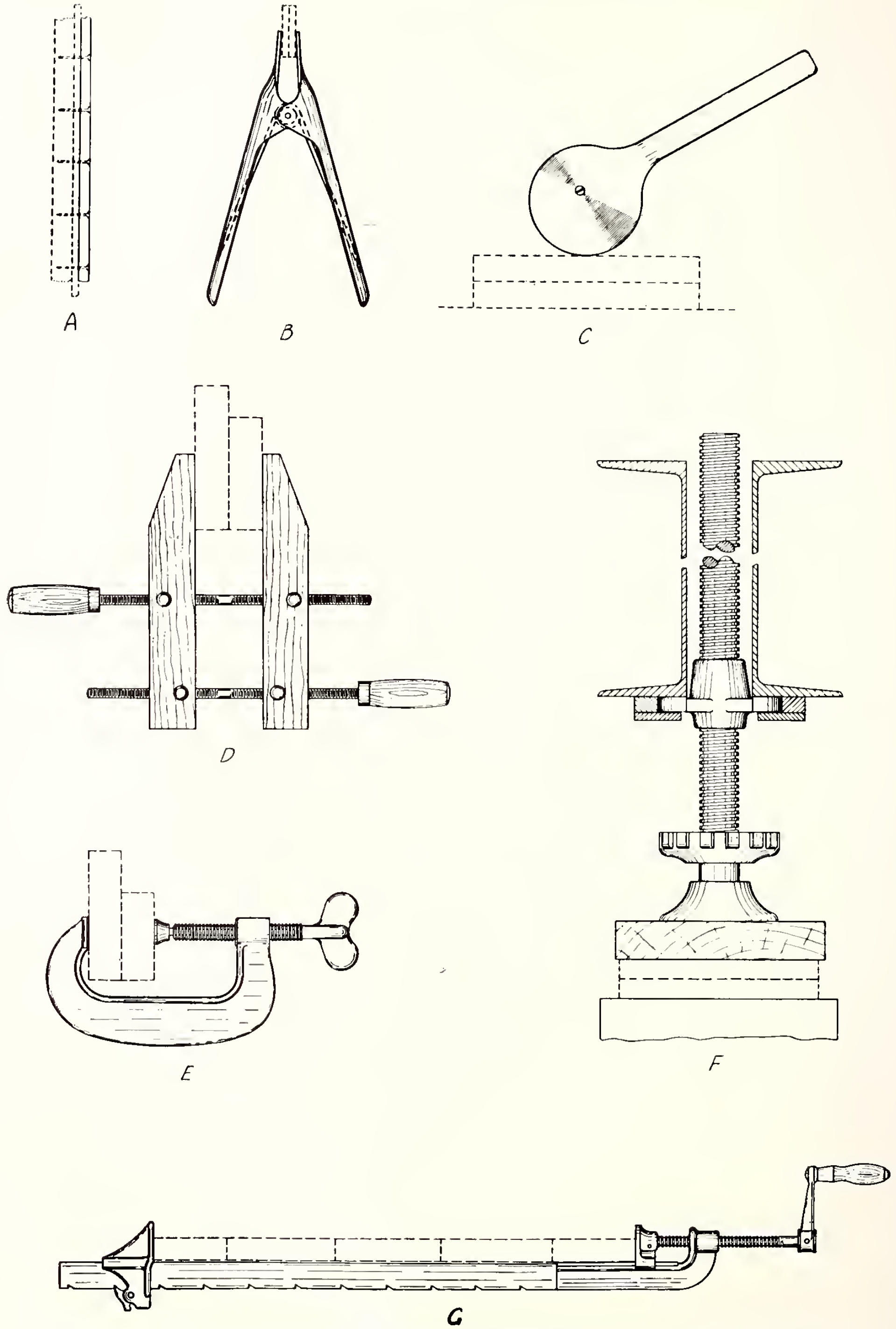


FIGURE 5–15.—Hand devices used in applying pressure to glue joints: *A*, brads, screws, or nails; *B*, spring clamp; *C*, eccentric clamp; *D*, wood clamp; *E*, C-clamp; *F*, jackscrews; *G*, bar clamp.

The approximate loads applied by screws of square threads may be calculated from the formula:

$$FL = WR\left(\frac{\pi fD+K}{\pi D-fK}\right) = \frac{WD}{2}\left(\frac{\pi fD+K}{\pi D-fK}\right)$$

where F is the force applied to the lever in pounds.
L is the length of the lever arm in inches.
W is the total load in pounds.
R is the mean radius of the screw in inches.
D is the mean diameter of the screw in inches $= \frac{1}{2}$ (diameter at root + outside diameter).
K is the pitch of thread in inches.
f is the coefficient of friction (may be assumed as 0.20).
π is $3.1416 = 22/7$ approximately.

TABLE 5–13.—*Pressure data on screw clamps and other devices used in gluing*

Equipment tested	Force applied	Length of lever arm	Pitch of screw	Diameter of screw	Total load [1]	Coefficient of friction
	Pounds	*Inches*		*Inches*	*Pounds*	
Jackscrew	[1] 170. 0	37	$\frac{1}{3}$	$1\frac{5}{16}$	33, 850	[2] 0. 1978
Do	[1] 170. 0	18	$\frac{1}{3}$	$1\frac{5}{16}$	16, 350	[2]. 1997
Do	[1] 170. 0	31	$\frac{1}{2}$	$2\frac{5}{16}$	16, 720	[2]. 2000
Do	[1] 140. 0	7	$\frac{1}{8}$	$\frac{7}{8}$	7, 500	[2]. 2498
C-clamp	[2] 70. 0	$1\frac{3}{4}$	$\frac{1}{8}$	$\frac{9}{16}$	1, 585	[3]. 20
Do	[2] 69. 5	3	$\frac{1}{8}$	$\frac{9}{16}$	2, 700	[3]. 20
Do	[2] 70. 2	2	$\frac{1}{5}$	$\frac{11}{16}$	1, 370	[3]. 20
Bar clamp	[2] 79. 9	$2\frac{1}{2}$	$\frac{1}{8}$	$\frac{1}{2}$	2, 810	[3]. 20
Wood clamp [4]	[2] 71. 3	$\frac{1}{2}$	$\frac{1}{14}$	$\frac{3}{8}$	[4] 720	[3]. 20

[1] Measured in test.
[2] Calculated from the formula given in section 5.251.
[3] Assumed from results of previous tests.
[4] Metal screws with V-type threads; hence calculation from formula is only approximate. The pressure developed by the wood clamp was measured with the work in approximately the position shown in figure 5–15. With the work closer to the screws a considerably greater load may be developed.

In using screws, the control of the amount of pressure involves a determination of the force applied. This will vary with individuals and, therefore, the use of a torque-indicating wrench or a lever arm which shows the force applied is recommended (fig. 5–16, *B*). In experimental gluing, the amount of pressure applied by screws can be measured by a hydraulic device, illustrated in use and plan in figures 5–16, *A*, and 5–17. The same device can be used for checking pressures in industrial operations, but it is not so well suited for continuous use in production and the torque-indicating wrench is preferable where adapted.

Various jigs have been developed for the assembly of various parts of aircraft and the application of pressure in gluing by either screws or hydraulic and air methods. A common fault in the design of jigs is that they are too light to carry the loads involved. It is recommended that the jigs be designed to carry at least 250 pounds per square inch over the entire gluing area in order to provide a reasonable factor of safety for the possible gluing of high density species where 200 pounds per square inch will be required. Where fluid pressure is employed, by means of hydraulic jacks or by liquid or air applied to the platen area, the loads are relatively easily determined from the unit pressure and the effective area to which the fluid pressure is applied. More detailed information on the application of pressures in specific operations is given under section 5.4.

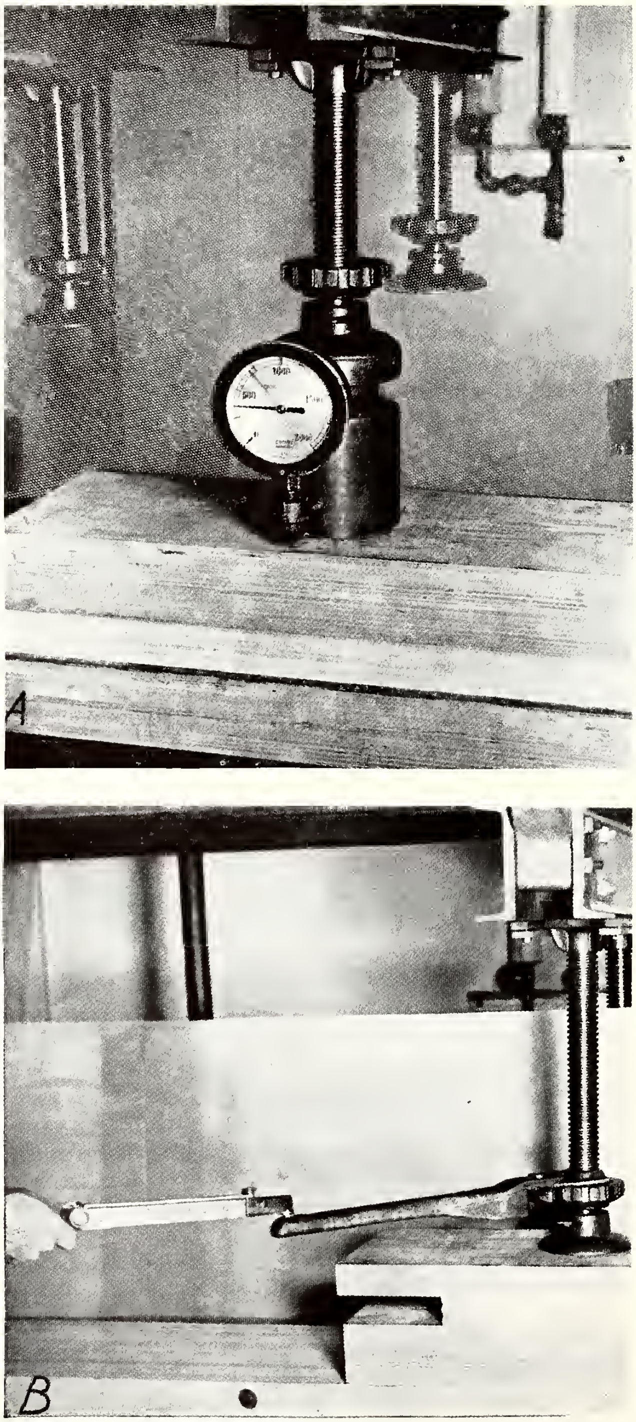


FIGURE 5-16.—Instruments used in measuring loads applied by jackscrews; *A*, compressometer; *B*, torque wrench.

5.252. Duration of Pressure. Joints should be retained under pressure at least until they have sufficient strength to withstand the internal stresses tending to separate the wood pieces. It is safe to assume that, under favorable gluing conditions, this stage will be reached in from 2 to 7 hours with cold-setting glues, according to the thickness and absorptive power of the wood. In hot-pressing operations, the duration of pressure may range from a few minutes to one-half hour or more, depending on thickness of material, temperature, and kind of glue and wood. A

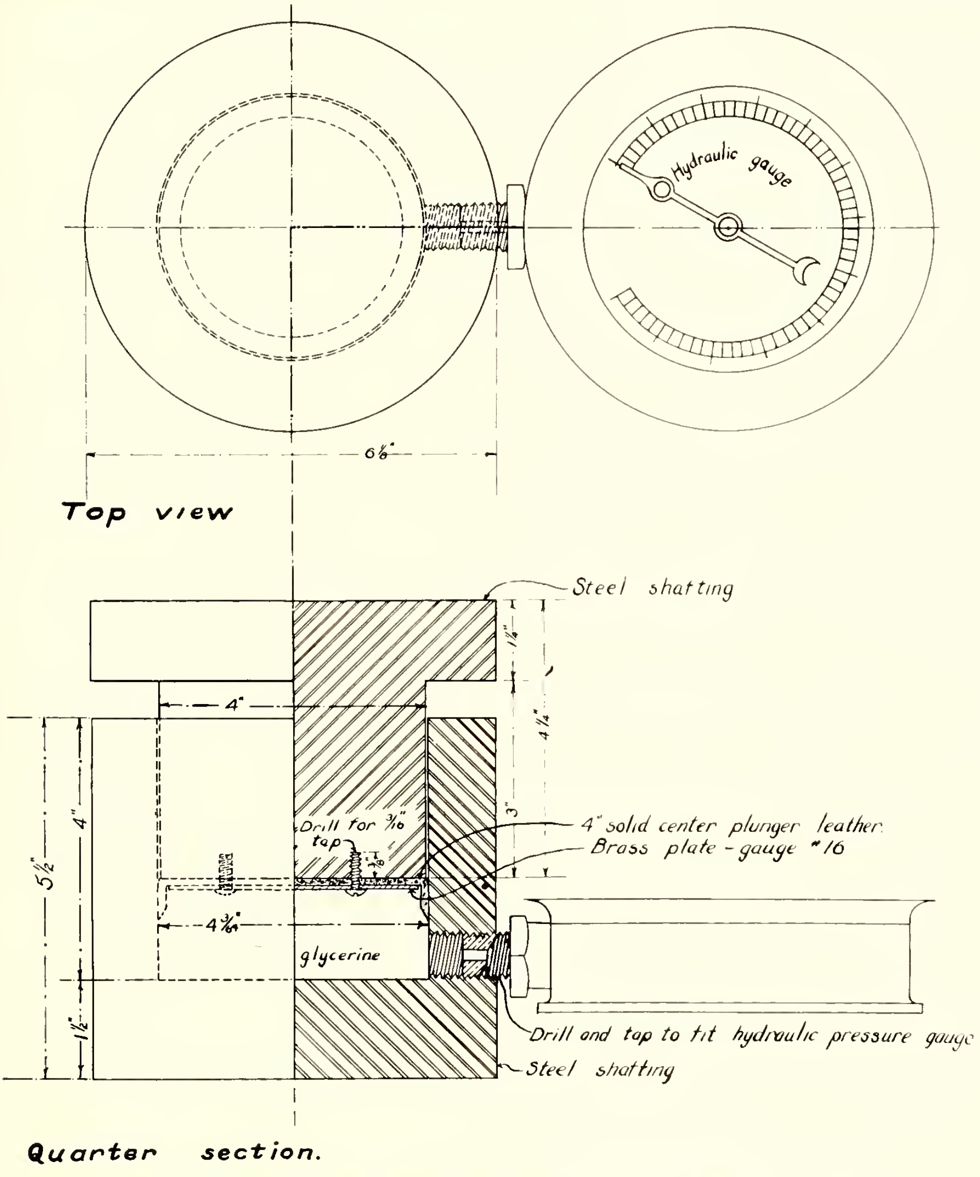


FIGURE 5–17.—Detailed drawing of compressometer; used to measure loads applied by jackscrews.

pressing period beyond the minimum is advisable and is usually provided for in directives and gluing recommendations.

The rate at which the joints gain initial strength is the principal factor determining the length of time in the press. Joints made with cold-setting glues increase in strength mainly as a result of chemical action and the drying of the glue layer, and drying in turn is affected by several factors. The quickest release of pressure is possible when a fast-setting glue, a thin spread, and warm, dry, thick layers of wood are glued in a warm room. The rate at which glues set is illustrated and discussed under section 5.262.

5.26. Gluing Temperature. Temperatures in the gluing operation should be controlled within recognized limits, which are governed largely by the characteristics of the glues. Temperature affects the working life of the glue solution, the permissible assembly period, the rate of setting of the glue, and the conditioning of the glued stock.

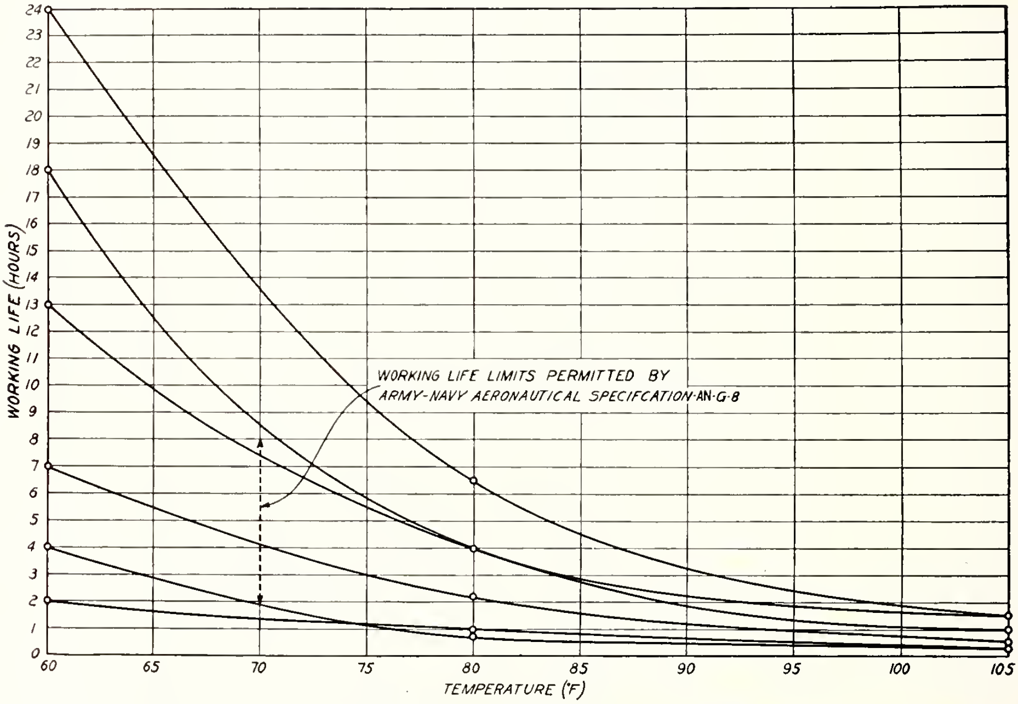


FIGURE 5-18.—Representative working-life curves for cold-setting, urea-resin glues. The minimum temperature at which cold-setting, urea-resin glues should be used is 70° F.

5.260. Effect on Working Life of Mixed Glues. An increase in temperature sharply curtails the working life of cold-setting, urea-resin glues. This class of glues forms gels and sets as a result of chemical action and loss of water. The chemical reaction will accelerate when the temperature rises. As a rough approximation, an increase of 10° F. in the temperature of the glue solution will reduce the working life by one-half. Figure 5-18 illustrates, for several different cold-setting, urea-resin glues, variations in working life that result from changes in temperature. A current Army-Navy Aeronautical specification (AN-G-8) limits the working life of cold-setting, urea-resin glues within the range of 2 to 8 hours at 70° F., but it is obvious from figure 5-18 that the temperature effect will still be present and must be recognized by the user if he is to avoid inconvenience. It is suggested that the user of a cold-setting, urea-resin glue either obtain from the manufacturer of the glue information on the working life at different temperatures, or develop this information for himself before the glue is used to avoid unnecessary waste and the inconvenience of cleaning equipment in which the glue has set. As mentioned elsewhere, it may be found advisable to keep the glue pot in a bath of cool water around 70° F. to prolong the working life of the mixture during hot weather.

The effect of temperature on the working life of casein glues is somewhat less marked than for cold-setting, urea-resin glues. As a general rule, a rise of some 20° F. is required to reduce the working life by one-half. In the average operation, where the glue is mixed at least twice each day, the user will ordinarily have no trouble with the casein glues that meet current specifications (Navy 52G8c, C–G–456, and Army Air Forces 14122). In hot weather, however, it may be advisable to observe some precautions, such as arranging to mix 3 or 4 batches of glue instead of 2 for each 8-hour shift. Limitations on the use of casein glues at lower temperatures are not very important, and the lower limit of the temperature of the glue room will probably be governed more by the comfort of the workers than by the characteristics of the casein glue.

The temperature changes involved under average operating conditions do not materially affect the working life of most hot-setting glues. However, these glues will thicken appreciably in the glue pot and on mechanical spreaders because of evaporation of solvent which is accelerated somewhat at higher temperatures. The working life of the resin-film glues is a matter of months under average operating conditions, but it is advisable to store them in cool dry places.

5.261. Effect on Assembly Period. The effect of the temperature of the gluing room and stock on the permissible assembly periods for casein and cold-setting, synthetic-resin glues is not critical. The desirable assembly period for these glues is limited largely by the initial thickening and drying that result from diffusion of the water into the wood or from evaporation. It is recognized that chemical reactions proceed more rapidly at elevated temperatures, but this is not so important as the rate of drying in limiting the assembly period. When the surfaces are laid together immediately after spreading (closed assembly), evaporation is greatly reduced and diffusion of water into the wood is the controlling factor. The rate of diffusion increases with the temperature of the wood, but the effect is not pronounced within the limits ordinarily prevailing in cold-gluing operations. Consequently, if the assembly period is adjusted within conservative limits, up to 20 minutes (table 5–12), it is usually unnecessary to make adjustments in assembly periods to compensate for changes in the temperature of the gluing room. If the operation is one in which the surfaces, after spreading, are exposed to the air (open assembly), both evaporation and diffusion increase with temperature. Again, however, if the assembly period is adjusted within conservative limits (table 5–12) further adjustments to compensate for changes in the temperature of the gluing room are ordinarily unnecessary.

The assembly periods are not so critical for glues that require the application of heat to effect their setting. Assembly periods for these glues vary from as little as ½ hour to several days or longer. For the high-temperature phenol, urea, and melamine formaldehyde glues it is usually recommended that sufficient time be permitted to elapse, between spreading and hot pressing, to permit evaporation of the solvent. For some low-temperature phenolic glues the pressure should be applied before the solvent has evaporated and for such glues the assembly time is more limited.

5.262. Effect on Rate of Setting in Joints. Temperature has a pronounced effect on the rate of setting of the glue and the rate of increase of joint strength. With both casein and cold-setting resin glues, the initial thickening that governs the assembly period is due largely to loss of water, but the final setting and the development of the strength and water resistance of the joint depend likewise on chemical changes in the glue, and both the chemical changes and the diffusion of water are accelerated by increasing temperature.

Figure 5–19, *A*, illustrates the rate of increase in the strength of joints made with a cold-setting, urea-resin glue on ¾-inch thick laminations of sugar maple and Sitka spruce with temperatures of the room and stock maintained at 75° F. During the initial period, the joints in the two species increased at about the same rate, but after 4 hours the rates showed increasing divergence. At the end of 4 hours, the strength of the joints was over 1,000 pounds per square inch, at which time the gluing pressure could have been removed without damage. Figure 5–19, *B*, shows the same data plotted with each test point expressed as a percentage of the final strength after 7 days of conditioning. At the end of 4 hours, for example, the joints in Sitka spruce had reached something over 80 percent of their final strength, while the joints in sugar maple had attained only about 40 percent of their final strength, yet the joints in sugar maple actually tested stronger at this period than the joints in Sitka spruce (fig. 5–19, *A*). This is because the shear strength of the maple is so much higher than that of the spruce.

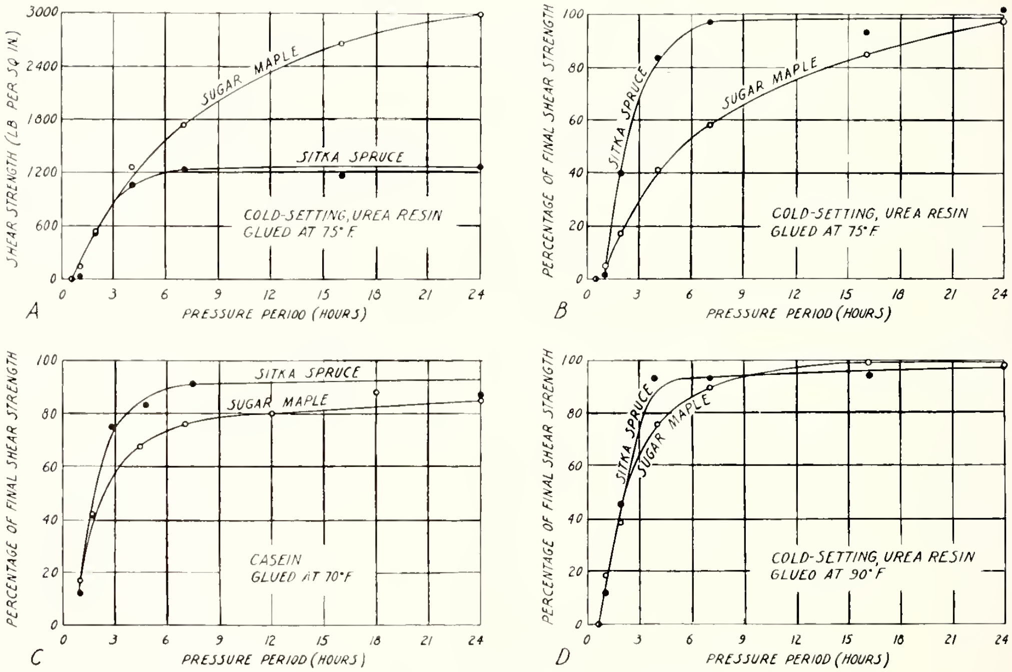


FIGURE 5–19.—Rate of increase in strength of joints made with cold-setting urea-resin and casein glues.

Figure 5–19, *C*, shows similar data for joints made with casein glue with the glue, room, and wood at 70° F. The rate of increase is obviously somewhat more rapid than that for the joints made with a cold-setting, urea-resin glue at 75° F. At the end of 3 hours, for example, casein-glue joints in Sitka spruce reached about 75 percent of their final value, while joints made with the resin glue reached about 65 percent. Over the same period, casein-glue joints in sugar maple reached something over 55 percent of their final strength and the resin-glue joints attained 30 percent of their final strength. A pressing period of 4 hours is considered suitable for either casein or cold-setting, urea-resin joints. The cold-setting, urea-resin glues do not set satisfactorily at temperatures below 70° F., and they should not be used on wood or in rooms at lower temperatures. Casein glues, on the other hand, will set at temperatures considerably lower than 70° F. but their rate of setting is greatly decreased. When casein glues are used at temperatures lower than 70° F., the joints should be kept under pressure for longer periods than are recommended for 70° F. and above.

A comparison of figures 5–19, *B*, and 5–19, *D*, illustrates the change in rate of increase in joint strength when the temperature of the gluing room and stock was increased from 75° to 90° F. At the end of the fourth hour, the resin joints in maple at 90° F. had reached over 90 percent of their final strength as compared to about 40 percent when the room and wood were at 75° F. This would correspond to actual test values of about 2,700 and 1,200 pounds per square inch, respectively. These data indicate that the gluing pressure can be removed after 2 hours at 90° F. just as safely as after 4 hours at 75° F.

Similar experiments carried out on birch plywood instead of laminated blocks have shown very similar trends in rate of increase in cold-setting, urea-resin and casein glue joints, with one additional point that is worth noting. The wet strength, as measured by testing after soaking in water for 48 hours, increases much more slowly than the dry strength; the casein-glue joints conditioned at room temperatures being particularly slow in developing their wet strength. This fact emphasizes the necessity for an extended conditioning period, at ordinary room conditions, before testing for water resistance. This point is of importance to those who have occasion to test glues rather than to those who use glues as a regular part of commercial production.

5.263. Use of Higher Temperatures. In many gluing operations, temperatures in excess of room conditions are required to set the glue or employed to reduce the time required for setting the usual cold-setting glues. Elevated temperatures are utilized in hot-pressing flat plywood, in bag molding, and in various assembly gluing operations to effect the cure or set of the glue in the shortest practical time. In these operations, the glues are spread and the assemblies laid up at ordinary room temperatures, but later heated by being placed in heated rooms, hot presses, autoclaves, or special assembly jigs heated by steam, hot air, electricity, or other means. All such operations involve the problem of heat transfer through the wood to the glue line as well as the temperature and time required to cure the glue properly. In all assembly gluing operations carried on at elevated temperatures, provisions should be made to prevent excessive drying of the wood during the heating period. Proper humidification of rooms is essential if assemblies are placed in heated rooms or chambers to accelerate or effect the cure of glues.

Determination of the temperature and time of heating required to obtain a satisfactory cure of the glue in joints is complicated because of the number of factors involved. In addition to the factors affecting the rate of penetration of heat through wood, (*5–12*), the problem is further complicated by the fact that the curing of synthetic-resin and casein glues does not take place at one exact temperature, but rather over a range of temperatures which differ for the different glues and for various formulations of the same type of glue. One resin glue, for example, may cure in 3 minutes at 300° F., in 6 minutes at 280° F., or in 20 minutes at 260° F. Other resins of the same basic type may cure as rapidly at the higher temperatures but fail to give satisfactory bonds when cured more slowly at lower temperatures or may even have an entirely different range of curing temperatures.

In view of the complications involved, the manufacturer's recommendations should be obtained on the time-temperature curing relations of the glue under consideration. These recommendations should then be checked by joint tests on each glue line in the assembly to see that all joints are receiving sufficient heat to cure them effectively. The recommendations may be checked further against the fundamental data on heat transfer (*5–12*) to see that the temperature conditions at the glue lines are those expected or preferably by taking thermocouple measurements of the temperatures actually obtained. The main reliance, however, should be placed on tests of joint quality in the assembly.

5.2630. Time-temperature Curing Relations of High-temperature Resin Glues. Approximate pressing periods for the glues classified in table 4–1 as high-temperature phenols, when used in conventional hot presses, without cauls, are given in table 5–14. The use of cold cauls with the veneer assembly will increase the required pressing period. This information is intended to serve as a rough guide and should be checked with manufacturer's recommendations and tests of joint strength. It is recognized that the recommended pressing periods tend to be slightly longer than the minimum time required to cure the majority of the glues belonging to this class, but the table is intended as a general guide and not as a fixed minimum recommendation. The schedules suggested in table 5–14 will not produce temperatures at the centers of thick panels equal to those at the centers of thin panels. Consequently, the suggested periods will not correspond exactly to data derived directly from fundamental heat-transfer equations. It is believed, however, that the use of the schedules will lead to the production of good joints, provided other gluing conditions are properly controlled.

When used in hot presses with platen temperatures of 255° to 265° F., other glues that set at high temperatures, such as melamine formaldehyde, hot-setting urea formaldehyde, and fortified urea formaldehyde, which can be cured at temperatures of about 240° F. or slightly above, will set in approximately the same periods given for the respective assemblies in table 5–14. In every case, however, the recommendations of the manufacturer should be obtained and the glue-joint quality determined by tests.

TABLE 5–14.—*Approximate pressing time for the gluing of panels with phenolic-resin glues when the platen temperatures are 300° to 310° F.*

Total thickness	No ply thicker than 1/10 inch		Core = 1/4 inch		Core = 1/2 inch	
	Depth to farthest glue line	Pressing time	Depth of farthest glue line	Pressing time	Depth to farthest glue line	Pressing time
Inch	*Inch*	*Minutes*	*Inch*	*Minutes*	*Inch*	*Minutes*
1/32	1/64	5	------	------	------	------
1/16	1/48	5	------	------	------	------
3/32	1/32	5	------	------	------	------
1/8	1/28	5	------	------	------	------
3/16	1/12	5	------	------	------	------
1/4	1/10	6	------	------	------	------
5/16	3/20	7	1/32	6	------	------
3/8	5/32	8	1/16	7	------	------
7/16	3/16	9	3/32	8	------	------
1/2	3/14	10	1/8	9	------	------
9/16	1/4	11	5/32	10	1/32	6
5/8	9/32	13	3/16	11	1/16	8
3/4	11/32	16	1/4	14	1/8	10
7/8	13/32	19	5/16	17	3/16	14
1	9/20	25	3/8	24	1/4	21

5.2631. Time-temperature Relations of Low-temperature Phenols. The low-temperature phenol-formaldehyde glues are relatively new and information on their time-temperature curing requirements is incomplete and inadequate. On the basis of existing information, however, it appears that they do not cure satisfactorily at temperatures below about 150° F. At temperatures of 140° to 200° F., the rate of cure is slow and long curing periods are required to insure high joint strength, such as: 16 hours at 140° F., 6 hours at 180° F., and 2 hours at 200° F. At temperatures above 200° F. these glues cure more rapidly. At a glue-line temperature of 240° F., one low-temperature phenol was found to cure sufficiently in 10 minutes to develop the full dry strength of 3-ply, 3/16-inch yellow birch plywood. At a glue-line temperature of 260° F., the same glue developed the full dry strength of the birch plywood in 5 minutes. The time required for the glue lines to reach the temperatures of 240° F. and 260° F. was about 4 minutes. At 280° F. the full strength of the birch plywood was developed in the time required to heat the glue line to this temperature.

5.2632. The Rate of Setting of Cold-setting, Urea-resin Glues at Elevated Temperatures. The rate of setting of cold-setting, urea-resin glues can be increased over that shown in figure 5–19 by the use of higher temperatures. Tests on a cold-setting urea-resin glue in 3-ply, 3/16-inch yellow birch plywood indicated that the time required to set the glue sufficiently to give a dry joint strength of 300 pounds per square inch decreases by approximately one-half for each 10° F. rise in temperature at the glue line. The same general relationship held for the heating periods required to develop 50 percent wood failure in the shear specimens. This degree of curing represents some 60 to 80 percent of the final joint strength but, with the cold-setting, urea-resin glues, final curing would ultimately occur at ordinary room temperatures. To achieve this state of cure required that the glue line be at 120° F. for 32 minutes, at 150° F. for 4 minutes, or at 180° F. for 15 seconds, after allowing a period of approximately 1¼ minutes for the glue line to reach the platen temperature. The time required for the glue lines to reach 200° and 220° F. was sufficient to set the glue fully.

The rapid rate of setting at the higher temperature emphasizes the danger of precuring that exists when the cold-setting, urea-resin glues are used in hot presses and heated assembly jigs. Their use at elevated temperatures should be limited to quick-closing single-opening hot presses and other pressure devices in which the required pressure can be reached in a few seconds. In addition to the danger of precuring that exists when cold-setting, urea resins are cured at temperatures above 200° F., there is some question concerning the effect of such temperatures on the glue. From the evidence available, it appears that their glue-line temperatures should not exceed 200° F. Whenever the cold-setting, urea resins are used at elevated temperatures, the manufacturer should be consulted and recommendations obtained on the maximum permissible heating temperatures.

5.2633. The Rate of Setting of Casein Glues at Elevated Temperatures. The rate of setting of casein glues is likewise accelerated at elevated temperatures, but to a lesser extent than in the case of the cold-setting urea resins. Tests on a commercial casein glue indicated that a joint strength of 300 pounds per square inch was obtained in 3-ply, 3/16-inch yellow birch plywood with the glue line at 120° F. for about 45 minutes, at 150° F. for 30 minutes, at 180° F. for 11 minutes, at 200° F. for 7½ minutes, and at 220° F. for 4 minutes. These times, of course, do not include the period of about 1¼ minutes needed to heat the glue line to the desired temperature. The time required to reach a shear strength of about 300 pounds per square inch was approximately halved for each 25° to 30° F. rise in temperature within the range of 120° to 220° F.

5.264. Electrostatic Heating. If wood is placed in an electrical field which oscillates at the frequencies used in the short-wave broadcasting range or higher,

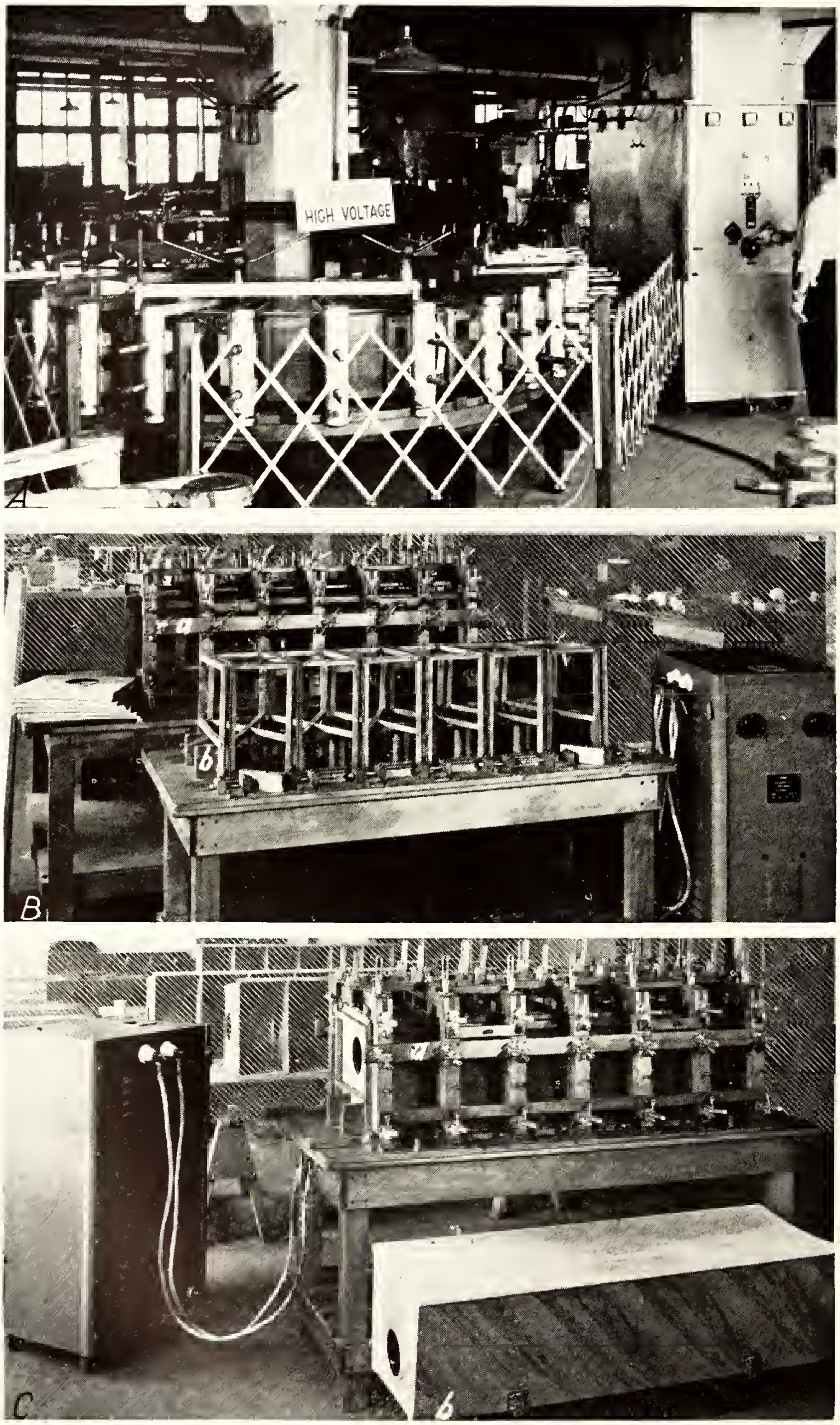


Figure 5-20.—High-frequency heating. *A*, Curved frame part being pressed and heated; *B*, jigs with electrodes for gluing glider seat, (*a*) exterior jig, (*b*) interior jig; *C*, (*a*) glider seat held in jigs while being glued, (*b*) finished seat.

heating occurs throughout the mass, thus making it possible to introduce heat at a rate dependent on the material to be heated and the capacity of the equipment available. The advantage of this method in contrast to heating by conduction is obvious.

Although this method has been introduced only recently into the woodworking industry in the United States, it is now gaining favor in the aircraft industry for rapid setting of the class of adhesives known as "cold setting," and in the curing of thermosetting glues. It appears to be especially well adapted to the gluing of thick laminated or plywood members, such as propellers, spars, or bearing blocks, with either thermosetting or thermoplastic glues, especially where the usual hot-plate methods are time consuming or impractical. The process has already been demonstrated on a practical scale and is in limited commercial use for the manufacture of plywood. It is now used in the gluing of compreg, the preheating of treated material that is to be compressed, and the gluing of airplane spars and other airplane parts.

The electrostatic heating apparatus is similar to that used in short-wave broadcasting, except that, instead of radiating the energy into space, the equipment is so designed that the energy is converted into heat within the mass of the wood occupying the high-frequency field. Units having an output of less than 7 or 8 kilowatts can be mounted on casters to serve several presses or jigs. A unit of 7-kilowatt output is shown in figure 5–20, *A*, and in figure 5–21, *B*. Smaller units are shown to the right in figure 5–20, *B* and *C*, and in figure 5–21, *A*, for lower heating loads. The machines are connected by flexible cable to electrodes suitably located in the press.

Several methods of applying the electric field for the gluing of wood have been employed (fig. 5–22).

If a metal press is used and there is sufficient opening to permit, the arrangement shown in figure 5–22, *A*, may be used, but there must be sufficient room for blocking between the press platens to prevent excessive energy losses to the press. When the opening of the press is limited, the arrangement shown in figure 5–22, *B*, may be used; in this case, two blocks are glued at a time. In the foregoing methods, the high-frequency field is applied perpendicularly to the plane of the glue joints, and the entire mass of the material is heated.

In certain cases, glue lines may be set selectively and very rapidly by applying the electrical field parallel to the glue joints. This method has been used to set edge joints in spars. An electrode covering the entire piece is shown in figure 5–22, *C*, and a relatively narrow electrode in figure 5–22, *D*. In either method, the electrical field is concentrated in the glue line, and, if sufficient field strength can be applied, the joint will develop its strength in 20 or 30 seconds without materially affecting the temperature of the main body of the wood. So far, only urea-resin glues have been used in this way. Phenolic-resin glues obviously cannot be completely cured by a heating period of such short duration, and the electric field tends to arc through the glue lines when such glues are used. The practical limits of distance through which the field may be applied successfully have not been determined, but the method would probably be applicable only to joint widths of perhaps 2 or 3 inches.

Since it is difficult to measure the temperature of glue lines when selectively heated it is necessary that the operator work out the electrode spacing, heating time, and field strength carefully before starting on the production of edge joints in quantity. Shear tests of the glue joints should be made throughout the length of the joint and the glue line should be carefully examined to be sure that the setting has been uniform and that no local overheating has occurred. The latter shows up in the glue line as a light brown discoloration or scorched appearance. If such areas occur the field strength or time should be reduced until they no longer appear.

An alternate method is illustrated in figure 5–22, *E*, in which the field is applied parallel to the glue joints in a member made up of several laminations. Where heat is applied to blocks glued with phenolic-resin adhesives, the temperature

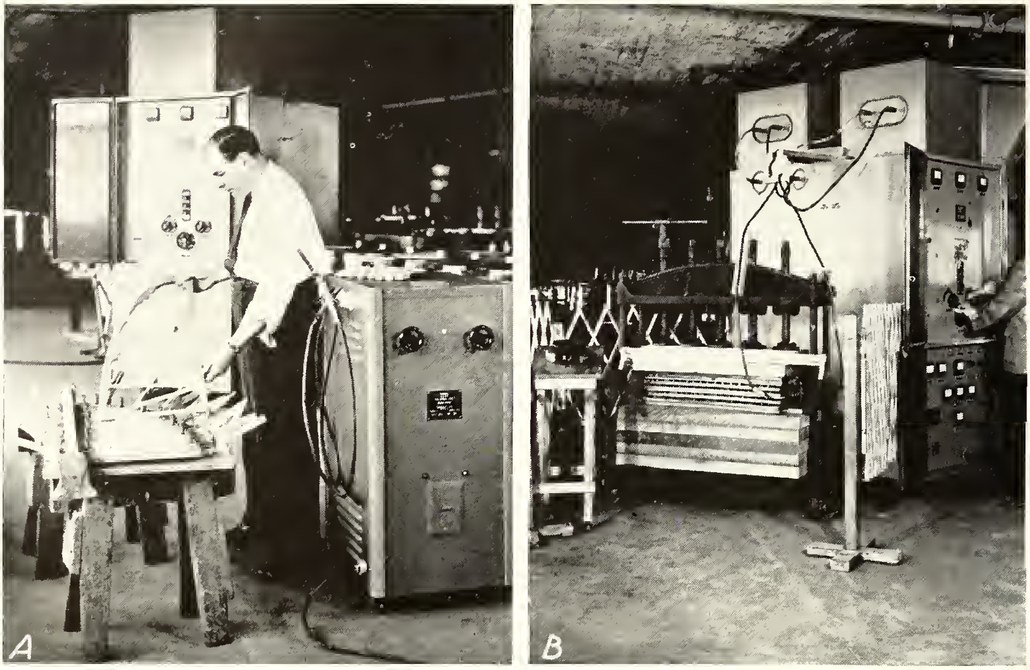


FIGURE 5-21.—High-frequency heating of wing rib parts. *A*, Single piece after removal from clamp press; *B*, multiple pressing and heating of wing rib part using large generator.

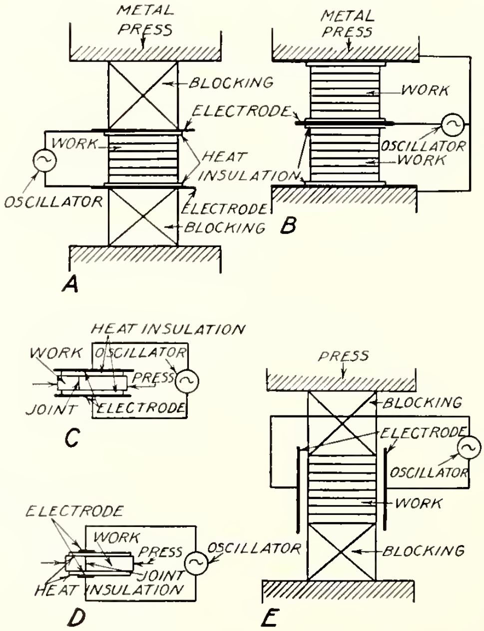


FIGURE 5-22.—Typical electrode arrangements for high-frequency heating.

should be raised at a moderate rate, so that the mass of the wood will be warmed and maintained as closely as possible to the curing temperature of the resin for the period required. Supplementary heating in a controlled humidity oven or room may be needed to produce an effective cure.

Experimental work indicates that oak containing moisture cannot be successfully heated by high-frequency energy at temperatures very much above the boiling point of water without danger of injury to the material; but if it can be first oven dried curing temperatures of approximately 300° F. may be used. This is of course not desirable for aircraft material since it would require a long time to bring the moisture content back to equilibrium with out-of-door conditions and swelling subsequent to manufacture might be objectionable.

Temperatures may be measured by placing thermocouples in the material under test. The leads outside of the load should be short and brought out parallel to the electrodes. The potentiometer should be disconnected while the electrical field is being applied. Ordinary thermometers may be used also, but they are probably subject to greater error and are not so convenient to use as thermocouples.

Insulation or spacers are desirable while heating in some instances in order to reduce heat losses and maintain surface temperatures. Where veneers are being glued, it is necessary to interpose a layer of plywood between the electrode and the work. Thus it is possible to cause the last glue line to be heated; otherwise, it would be cooled by loss of heat to the electrode. Insulation along the sides of wood being heated will greatly reduce radiation as well as equalize the heat throughout the work. For example, if the material in the press receives more heat at the central zone than at the edges, the thermal expansion will be greater in the center than along the edges thus causing open joints and inadequate pressure. The insulation should be included in the high-frequency field and may be made of a low-density material or of a rim of the material being heated. Another method of accomplishing the same result is to heat the space surrounding the wood in order to reduce heat losses from the work. Heated electrodes; of course, make insulation unnecessary.

5.27. Gluing Different Species and Surfaces of Wood. Figure 5–23 shows the results of gluing tests on 15 species, including those most commonly glued in aircraft, with casein and cold-setting, urea-resin glues. The results with casein glue are a part of a larger series of tests on 40 different species (*5–17*).

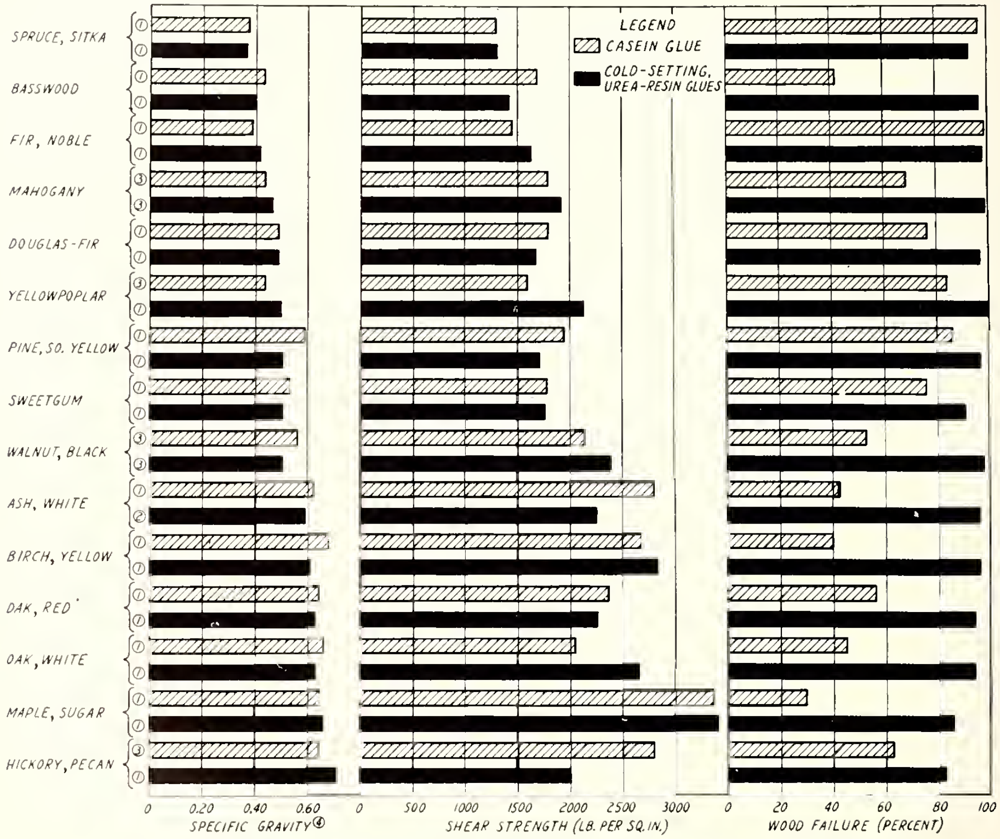
The wood glued with the cold-setting resins had 11 to 12 percent moisture content, and the joints were conditioned before test to the same moisture content. The wood glued with casein glue had from 6 to 7 percent moisture content, and the joints were conditioned to about 7 percent before test. The joints were tested in shear by the regular method approximately 7 days after gluing (sec. 4.3).

The strengths of the joints of the various species varied in general with the specific gravity of the wood, as is normally expected, and there is no consistent difference in the strength of the joints for the two types of glue. The strength values have not, however, been adjusted to a common moisture content basis; hence, the strengths for the casein-glue joints should tend to be somewhat higher than those for the resin-glue joints. The principal significant difference in test values is in the percentages of wood failure shown in the broken specimens. The percentages of wood failure in the resin-glue joints are much higher on the high-density species than in the casein-glue joints. Approximately the full strength of the species was developed, however, with both types of glue.

In general, the low-density species are more easily glued with all woodworking glues than are the high-density species. With high-density species, such as yellow birch, hard maple, and hickory, the production of glue joints that develop the full strength of the wood and that are durable under severe exposures requires more careful control of gluing conditions than with low-density species, such as spruce and yellowpoplar.

Although freshly planed surfaces of most of the woods used for aircraft present no special gluing problems, difficulty may be experienced with plywood of different species and densities. The nature of these unfavorable surface conditions, most of which develop during plywood manufacture, and corrective measures are discussed under section 5.212.

5.270. Recommendations for Gluing Side-grain Surfaces of Different Species. Certain recommended gluing conditions are similar for all species, but variations in other conditions are necessary for best results. The amount of glue spread and moisture content of the wood at the time of gluing need not be varied. The permissible assembly periods are likewise similar for most species and are within the limits given in table 5–8. Moisture diffuses more rapidly into the sapwood than into the heartwood of most species and, while there is considerable difference between species in this respect, these differences are not important if the assembly periods are kept within the recommended limits. Some change in viscosity of glue, particularly for casein, is advisable when gluing high-density species, such as birch, beech, maple, and hickory. A 5 to 10 percent decrease in water content over that recommended for low- and medium-density woods is usually sufficient and aids in preventing starved joints for species with which high pressures are normally used.



① - MIXED HEARTWOOD AND SAPWOOD OR NOT IDENTIFIED. ② - MOSTLY SAPWOOD. ③ - MOSTLY HEARTWOOD.
④ - BASED ON THE OVEN-DRY WEIGHT AND THE VOLUME AT APPROXIMATELY 12% MOISTURE CONTENT.

FIGURE 5–23.—Results of tests on joints of various species glued with casein and cold-setting, urea-resin glues. Joints tested in the regular block shear test (sec. 4.3). Each test value based on 60 or more specimens.

The pressures recommended for gluing various aircraft woods vary considerably. Pressures should be sufficient to produce joints of high quality but should never exceed the crushing strength of the least dense species in the assembly. With fluid pressures and nail gluing, there are definite limitations on the pressures that can be used, and adjustment for species differences is rarely possible. With other pressure devices, such as jackscrew and hydraulic presses, however, the species consideration is important. From the standpoint of the pressures that produce the best glue joints, the aircraft woods can be divided roughly into three groups, with recommended gluing pressures as follows:

GROUP I	GROUP II	GROUP III
200 to 250 pounds per square inch	*150 to 200 pounds per square inch*	*100 to 150 pounds per square inch*
Ash, white.	Sweetgum.	Basswood.
Hickory and pecan.	Sycamore.	Cottonwood.
Maple, hard.	Walnut, black.	Fir, noble.
Birch, yellow.	Elm, American.	Hemlock, western.
Beech.	Douglas-fir.	Pine, ponderosa, sugar, and white.
Oak, white.	Mahogany.	Port Orford white-cedar.
	Magnolia, southern.	Redwood.
	Maple, soft.	Spruce, red, Sitka, and white.
	Tupelo, water.	Yellowpoplar.

The crushing strength of wood decreases rapidly with increase in temperature and moisture content. At room temperatures and moisture contents of 8 to 12 percent, the crushing strength of the aircraft woods is considerably higher than the above recommended gluing pressures, which have been found satisfactory for the production of high-quality glue joints. But, at the temperatures used in manufacturing hot-press plywood and at higher moisture contents, the crushing strength of wood is much lower. These considerations are important and must be taken into account in the manufacture of aircraft plywood. Some of the low-density species in particular, which will withstand 150 to 200 pounds per square inch in cold-pressing operations, will be compressed considerably at pressures of 125 to 150 pounds per square inch in hot presses operated at temperatures of 310° F.

Whenever species of widely varying densities are glued together, the conditions recommended for the heavier species should be approached as closely as possible but the pressure should be adjusted so as to avoid crushing of the least dense wood in the assembly.

5.271. Gluing End-grain Surfaces. The methods, practices, results of tests on joints, and recommendations which have thus far been presented relate more specifically to the gluing of side-grain surfaces of wood. Such surfaces are involved exclusively in plywood and laminated constructions. Joints between side-grain surfaces in most species can be made as strong in shear parallel to the grain, tension across the grain, or cleavage, as the wood itself. The highest stresses developed in these joints do not exceed 3,000 or, at the most, 4,000 pounds per square inch.

The gluing of end-grain surfaces, on the other hand, is not accomplished with the same degree of success. Straight end-grain butt joints are rarely attempted in any type of construction, and, where wood is subjected to tension stresses parallel to the grain, joints of this type cannot be depended upon to develop more than a small part of the strength of the wood.

Most North American species of wood are capable of withstanding 6,000 to 20,000 pounds per square inch in tension parallel to the grain. Tests made in gluing straight end-grain surfaces have shown that such joints are erratic and rarely exceed about 3,000 or 4,000 pounds per square inch in strength. Their strength is limited by several factors, including (1) structure of the wood, (2) penetration of the glue,

(3) air bubbles in openings of the wood, (4) quality of glue, (5) consistency of glue, (6) application of glue, (7) amount and duration of pressure, and (8) shrinkage of glue. Since factors 1, 3, and 8 are largely beyond operative control, any improvement in strength must be brought about primarily through the other factors.

With even the most careful gluing of straight butt joints, not more than about 25 percent of the tensile strength of the wood parallel to the grain has been obtained in tests. It is evident, therefore, that in order to obtain a tensile strength of the various species that is greater than 25 percent of the tensile strength of the wood, a scarf or other form of joint must be used instead of plain end gluing. Where it is necessary to elongate members, such as longerons or spars, some such form of joint is recommended. The plain scarf (fig. 5–34, *A*) is perhaps the easiest to glue and involves fewer machining difficulties than the many-angle forms of joints.

Excessive penetration of glue may occur when gluing end-grain surfaces such as scarf joints. This is more likely for hardwoods with large vessels or pores than for conifers or softwoods. Excessive penetration is more of a problem with thin glues than with thick glues and with high pressures than with low pressures. It is recommended that, for gluing scarf joints and other end-grain surfaces, a glue mixture be used that is somewhat thicker than that used for gluing side grain. For most of the cold-setting glues, the use of a glue mixture containing about 10 percent less water than is normally used for side-grain gluing is satisfactory. A reduction in water content is not recommended for those glues that are normally quite thick or viscous. Both surfaces should be coated with glue, and other conditions favorable to the production of strong joints should be observed.

In some cases, particularly with the dense, porous hardwoods, sizing the end-grain surfaces may prove beneficial. The size should be made by diluting the glue to be used in the final gluing operation with 50 percent more water than is recommended for side-grain gluing. It is not necessary to allow the size coat to dry completely before final gluing. Sized scarf joints should be glued with the same glue used in sizing but containing about 10 percent less water than for side-grain gluing.

Without reinforcement of some type, glue joints between end-grain and side-grain pieces cannot be relied upon where strength requirements are important. Such joints are commonly made in aircraft production, but wherever they are to be subjected to considerable stress they are reinforced with corner blocks, plywood angles, or plywood gussets.

5.272. Gluing Modified Wood Products. The gluing of modified wood products, such as resin-impregnated wood (sec. 3.31), heat-stabilized wood (sec. 3.4), resin-impregnated and compressed wood (sec. 3.32), and resin-impregnated laminated paper (sec. 3.5), involves several considerations in addition to those described for the gluing of normal wood. Particular attention must be given to the preparation of surfaces and some consideration to the selection of glues.

5.2720. Impreg and Heat-stabilized Wood. Resin-impregnated, uncompressed wood, such as impreg, can be readily glued with acceptable aircraft glues under the conditions described for the denser aircraft species (sec. 5.27). Preliminary tests on heat-stabilized wood indicate that it likewise can be glued satisfactorily under conditions described for high density species. Thick laminations of either type, that do not deform readily under pressure, should be carefully machined before gluing to insure smooth, true surfaces. Thin laminations that cannot be planed or otherwise machined should be machine sanded with No. 1–0 or hand sanded with No. 3–0 garnet paper or its equivalent before gluing.

5.2721. Compreg. Resin-impregnated compressed wood products, such as compreg, are more difficult to glue than are impreg products and it is essential to the production of high quality glue joints that special precautions be taken in the preparation of surfaces and selection of glues. At the time of manufacture, the surfaces of these products are glazed and coated with resin. Woodworking glues do not adhere satisfactorily to such glazed and resinous surfaces. The surfaces of thin laminations, which deform readily under pressure, can be brought to a satisfactory gluing condition by thorough hand or machine sanding. For hand sanding, the equivalent of No. 2–0 garnet, and for machine-sanding the equivalent of No. ½ or No. 1–0 garnet paper have been found to give good results. Laminations thicker than one-quarter inch, which do not deform readily under pressure, must be surfaced on planers, jointers, or metal milling machines to produce surfaces that are true, smooth, and free from glaze. Variations of more than 0.003 inch should not occur on the surfaces. When heavy members of such modified wood products are glued together, as in propeller manufacture, the necessity of having uniform and well-fitted surfaces cannot be overemphasized. Serrated side grain joints have been used in gluing heavy compreg laminations.

In operations permitting their use, the high-temperature-setting resin glues have been found to give satisfactory joints between compreg members. The use of these glues, however, is limited to thin laminations, which can be glued in hot presses, and to thick laminations glued by special processes (sec. 5.264). Compreg-to-compreg joints can likewise be made with low-temperature phenolic glues under proper curing conditions (sec. 5.263). For cold-press gluing operations the cold-setting, urea-resin glues have been found to bond compreg members satisfactorily and to be superior to casein glues for this purpose (*5–10*).

Lighter glue spreads are permissible but assembly periods are about the same as those for normal woods. Pressures of 200 to 300 pounds per square inch should be used to insure adequate contact, particularly on thick laminations. Because the diffusion of moisture into compreg is slower than into normal wood, it is advisable to leave the assemblies under pressure longer than is recommended for normal wood (sec. 5.250). In contrast to the gluing of compreg laminations to each other, the gluing of normal wood to compreg presents fewer difficulties. In making compreg to normal wood joints, the compreg should be carefully machined or lightly sanded depending upon the thickness of lamination. Glue spreads and assembly periods should be normal and the maximum pressure permitted by the normal wood without crushing should be applied. The cold-setting urea resins appear to be somewhat better adapted to the gluing of normal wood to compreg than are the casein glues. Resin glues, which require the application of higher temperature to effect their setting, have been successfully used to make normal wood to compreg glue joints.

5.2722. Papreg. Papreg can be satisfactorily glued to papreg and to wood with all acceptable aircraft glues if precautions are taken to first lightly sand the surfaces of the papreg. This can be accomplished by machine sanding with the equivalent of No. 1–0 garnet or hand sanding with No. 2–0 garnet paper. For the liquid hot-press glues in particular, the assembly period should be somewhat longer than for wood in order that the solvent may fully evaporate and blistering during hot pressing be avoided. Good quality joints between papreg and papreg and between papreg and normal wood have been made with pressures of from 25 to 250 pounds in the case of liquid glues meeting aircraft specifications. The thickness of the members largely determines the pressure required to insure good contact. It has been difficult to obtain good bonds in nail gluing of papreg to normal wood because of the formation of a bur when the nail passes through the papreg, which appears to prevent good gluing contact. Preboring of nail holes may be necessary to obtain satisfactory bonding of papreg by nail gluing.

5.28. Conditioning Glued Stock. Cold-gluing operations add moisture to the wood in varying percentages (table 5–11). Glue that has set in joints contains only a part of the water added at the time of mixing, the remainder having been absorbed by the wood or removed by evaporation. The absorbed moisture must be allowed to dry out or to distribute itself through the wood in order to insure the full strength of the joint and to reduce the tendency of the glued member to warp.

In gluing thick laminations, the moisture from the glue need not be eliminated but may simply be allowed to distribute itself throughout the construction. Complete equalization would require a very long time. For black walnut and white oak in laminations about three-quarters inch thick, and under average room temperatures, a conditioning period of 7 to 10 days is sufficient. For woods which permit a more rapid distribution of moisture, such as spruce, a 3- to 5-day period should suffice under most conditions. Where heavy constructions are glued from laminations one-eighth inch or less in thickness, however, they will normally contain too much moisture after gluing and should be dried for 1 to 3 weeks or longer, depending upon their thickness and width and the conditions of drying.

The drying of plywood panels and other thin structures after they have been glued with cold-setting glues is a problem in which simplicity of control and operation are important. Although such panels can be dried successfully under widely varying conditions of temperature and humidity, the effect of the drying schedule upon the joint strength may well be considered. It has been found possible to dry panel stock satisfactorily at a constant temperature and a constant humidity corresponding to a moisture content about 2 percent below that which the panels are to reach. Thus, if the panels are to come down to 10 percent, a humidity corresponding to about 8 percent moisture content would be used (fig. 5–6). The time required may range from a few hours with thin material to 2 to 3 days with thick-panel material. At a temperature of 120° F., the humidity corresponding to 8 percent moisture content is about 50 percent. A temperature of 120° F. and a humidity of 50 percent will dry a panel, one-half inch thick, to 10 percent moisture content overnight, and no particular damage will result if the stock is left in the kiln appreciably longer, since the drying rate below the desired 10 percent will be increasingly slow.

Table 5–15 shows several combinations of temperature and relative humidities with which a moisture content of 8 to 12 percent may be obtained in freshly glued plywood within a reasonable drying period, when stickered to obtain a free circulation of air.

TABLE 5–15.—*Combinations of temperatures and relative humidities suitable for drying cold-pressed plywood and assemblies to various desired moisture content values*

Moisture content desired [1] (percent)	Relative humidities for use with the temperatures indicated			
	100 °F.	110° F.	120° F.	140° F.
	Percent	*Percent*	*Percent*	*Percent*
8	33	35	37	41
10	46	48	50	53
12	58	59	61	65

[1] Relative humidities and temperatures given correspond to an equilibrium moisture content about 2 percent below that which the panels are to reach.

5.281. Hot-pressed Plywood. Plywood and other members glued on hot presses commonly have only 2 or 3 percent moisture content when removed from the press. Such material should be conditioned to 8 to 12 percent before it is assembled into aircraft parts and structures. This may be done in conditioning rooms in which a relative humidity is maintained which is approximately equal to or slightly in excess of that corresponding to the desired moisture content. Another method is to apply sufficient water to the hot-pressed panels to bring them to the required moisture content and then to stack them solidly, allowing the moisture to equalize throughout.

Care should be used to apply only sufficient water to bring the panels to the desired moisture content. The correct amount of water can be readily calculated after determining the moisture content and weight of the dry panels. The moisture is conveniently applied by passing the panels between water-covered rolls, such as in a glue spreader, or by spraying. By weighing a number of panels before and after the application of the water, the amount and uniformity of the application can be checked. The time required for equalization in the solid piles again varies with the thickness of the individual panels. While the panels are usually warm when the water is applied, a circumstance which aids equalization, the glue lines, especially of synthetic-resin glues, retard diffusion. Conditioning periods for plywood of different thickness and number of plies should be based on actual moisture content determinations of both the interior and exterior plies.

5.282. Conditioning Bag-molded Plywood. The moisture content of plywood and other structures produced by most bag-molding methods is not changed greatly during the gluing, unless there is a leak in the bag. Consequently, veneer and other parts that are assembled dry and kept dry during gluing need to be conditioned for only a few hours to bring about an approximate equilibrium moisture content. In case of a leak in the bag, however, the molded structure may have a high moisture content and require careful drying for a longer period. The drying conditions shown in table 5–15 are considered satisfactory for most molded products.

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5.3. BAG MOLDED PLYWOOD AND STRUCTURES.

5.30. General. The molding of plywood by means of fluid pressure applied through flexible bags or blankets of some impermeable material (bag-molding) has found application in the making of airplane parts of various degrees of curvature. In size, these parts may vary from a fairing for a tail wheel to a half fuselage complete with bulkhead rings. They include all combinations of single and compound curvature, cylinders, paraboloids, portions of a sphere—in short, any curved piece for which a mold can be made and later separated from the finished product.

Bag-molded parts, such as fuselages, wing fillets, and fairings, are reported to offer improved performance characteristics as a result of the superiority of the stiffness-weight ratio of molded plywood to that of metal, and the smooth ripple- and rivet-free surfaces presented to the air stream (fig. 5–24).

Bag molding of plywood and laminated veneer members probably had its origin in the vacuum-bag process that was introduced in the furniture industry several years ago (fig. 5–25, A). While the vacuum-bag process depended upon atmospheric pressure and ordinarily only room temperature to set the glue between the plies, the newer techniques employ higher fluid pressures and varying degrees of heat.

Misnomers, such as "plastic plywood" and "plastic planes," have been applied to structure of molded plywood that are actually made from wood bonded with synthetic resin adhesive. By weight, these structures are probably about 80 percent wood and 20 percent resin adhesive. Except for variations in shape, the product is essentially the same as flat-press plywood.

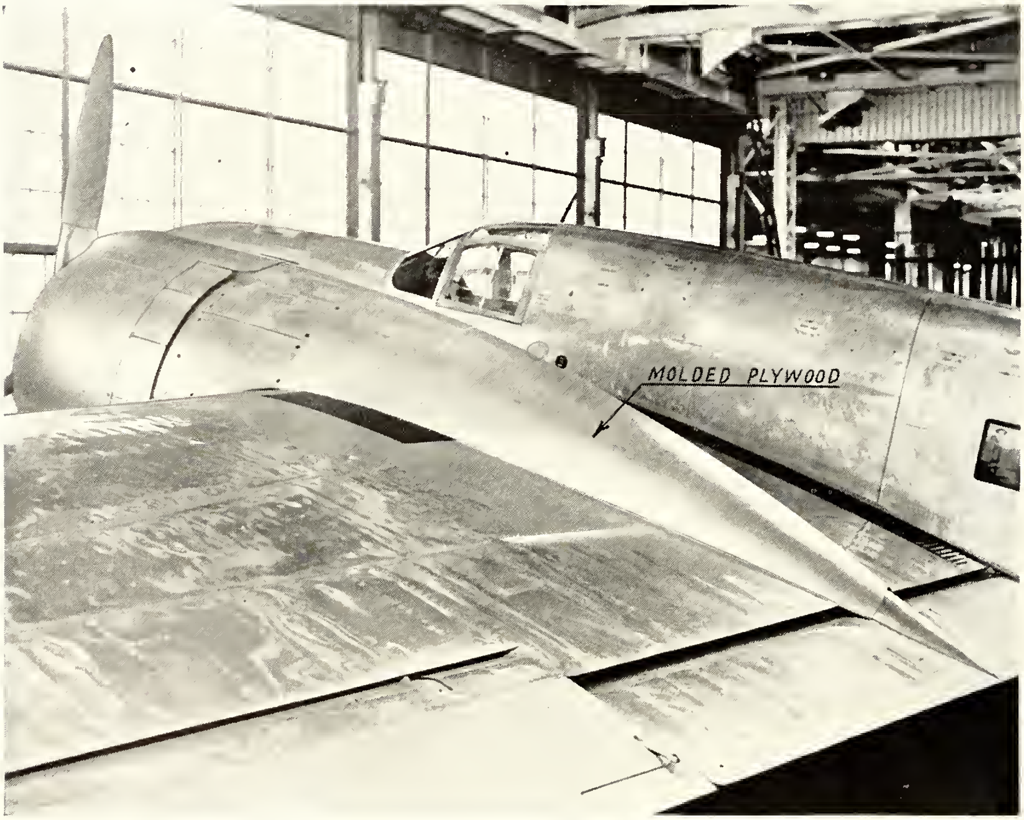

Figure 5–24.—Rear section of engine cowling of molded plywood. Note smooth plywood surface as contrasted with riveted metal wing and fuselage skin.

5.31. Methods of Bag Molding. Molded plywood is produced by several techniques which are often referred to specifically, such as the Duramold, Vidal, Aeromold, or vacuum-bag processes. Other terms sometimes used in describing the technique are "bag molding," "autoclave molding," or "tank molding." Perhaps the most inclusive is the term "fluid-pressure-molding." Five general methods are shown in figure 5–25.

The fundamental procedure is the same for all processes in common use. In principle the technique consists of attaching temporarily by staples, tape, clips, or some other means, superimposed layers of strips or sheets of glue-coated veneers to a mold of the desired shape, and molding these into a unit structure by the application of heat and fluid pressure through a flexible, impermeable bag or blanket. All the processes are relatively simple and provide a means by which plywood of simple or compound curvature, and of constant or varying thickness, in any arrangement of plies can be produced. Naturally, flat plywood can also be made by bag molding, but due to the critical bag materials required in most operations, it is recommended that the technique be limited to the production of strategic molded parts that can be manufactured by no other practical means. In general, parts that fall in this category will have one or more of the following characteristics: Appreciable compound curvatures; variable thickness; single curvature bends approximating or exceeding 180° when pieces are too thick to be steam bent from flat plywood; parts too large to be made practicably by mating dies; quantity too small to justify mating dies.

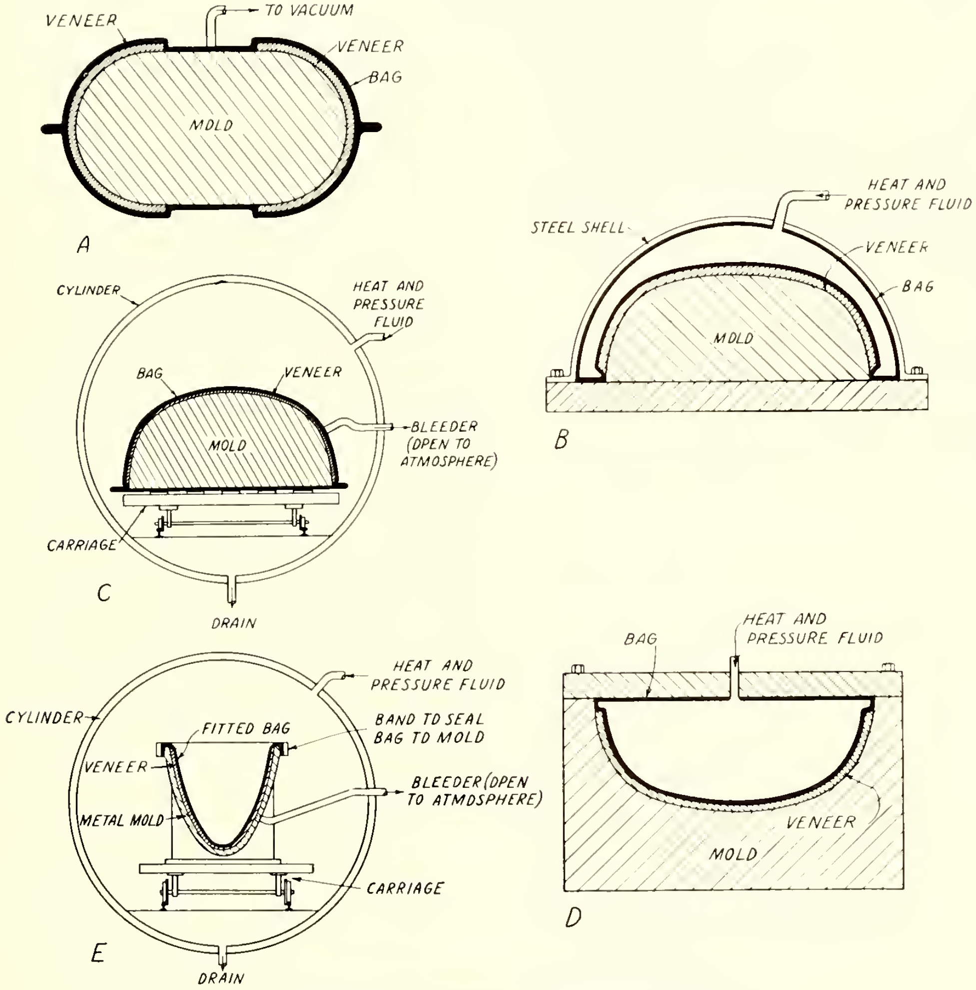

Figure 5-25.—Five methods of forming bag-molded plywood.

5.32. Equipment for Bag Molding.

5.320. Molds. The forming of any piece of bag-molded plywood requires a mold of some type. Molds, sometimes called forms, dies, or mandrels, are broadly classified as male or female. Male molds as illustrated in figure 5–25 *A*, *B*, and *C* are the desired shape on convex surfaces, while female molds (fig. 5–25, *D* and *E*) have the proper shape on concave surfaces.

Common mold materials are wood (solid or plywood), metal (steel, cast iron, or low-temperature alloys), plastic materials, and cements. The choice of mold materials will depend largely on the shape of the item to be molded, the quantity desired, and the availability, advantages, and disadvantages of the materials considered.

5.3200. Wood Molds. Wood molds are commonly made of lumber of softwoods such as western white pine or sugar pine, cut approximately to the contour of the mold and glued and nailed together. The rough shape, usually not more than 6 inches thick at any point, is then marked into stations—a procedure very similar to that used in defining the shape of a boat—and worked down by plane and sander to the desired shape minus an allowance for a hardwood skin. This hardwood skin (often of birch veneer) is bonded directly to the mold by bag molding and is later worked carefully down to the exact contour at each station. Attention is given to the direction of the grain in both the skin and the mold proper so that the maximum cross-banding effect is secured.

Wood molds are distorted somewhat by moisture and heat. A leaky bag is particularly damaging to a wood mold and usually ruins the piece being molded, as well. Overheating the mold will also hasten the distortion and necessitate early recontouring or other repair. Much of this distortion and cracking is caused by exposing the hot surface of the mold to the air after the removal of the molded piece from its surface. By cooling the mold while in the bag this rapid surface drying can be eliminated. Cooling can be done by a cold water spray system in the cylinder or in a special cooling booth installed near the cylinder.

Plywood molded on thick wood molds heats more slowly than the same thickness and construction on thin steel molds. The time required to mold the piece, therefore, is about twice as long as for the same construction on a thin steel mold.

A variation of the wood mold construction that may be referred to as a "plywood-shell mold" is sometimes used on shapes such as that of a large nacelle. These molds [5] are produced on a master mold of the usual cross-banded lumber. The shell mold itself is similar to the finished molded plywood article, only much thicker (¾ to 1½ inches) depending upon its size and the degree of curvature. The face veneers of these molds are sometimes impregnated with resin which is cured at the time of bonding.

Another construction that should produce a more stable mold involves the use of thick, resin-bonded plywood instead of solid wood stock in the body of the mold, with an impregnated skin of veneer bonded to the plywood base. The plywood should be laid so that its shrinking and swelling in thickness will introduce the least serious dimensional changes in the mold.

Wood molds are almost always male in shape, which necessitates fastening the strips of veneer to the mold to hold them in place. This is readily done by means of staples or tacks that must later be removed.

Wood molds are well adapted to the formation of a molded plywood skin and its bonding to stiffeners or bulkhead rings in a single operation. In this process the ribs are preformed by laminating or steaming to exact shape.[6] They are inserted in previously cut slots in the face of the mold before the veneer strips are tacked in place. The fit of the ribs in these slots is important. If the slot is too deep, the finished molded part will show a depression at this point and the glue bond between the skin and the rib may be questionable. If the slot is too shallow, the rib will project beyond the surface of the mold and a bulge will be produced in the skin.

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[5] A patent application on the details of one type of plywood shell mold is reported to have been made by John S. Barnes, Skaneateles, N. Y.

[6] It is reported that applications for patents have been made on details of a similar process by the Vidal Research Corporation.

5.3201. Metal Molds. Metal molds are usually made of steel sheet or cast iron. Alloys having low melting points are also reported to be in limited use. Molds of single or very slight double curvature are made of sheet material one-tenth to one-fourth inch thick, while those of severe double curvature, such as for a propeller spinner, are cast. In most cases, metal molds are of the female type in which the strips of veneer are taped together or sprung in place between metal clips, as illustrated in figure 5–26, thus eliminating the necessity of a tacking surface to which material can be stapled.

Metal molds, particularly those of sheet metal, have the advantage of very rapid heat transfer. The rate of temperature rise in a molded plywood piece on a thin metal mold approaches that of plywood of the same thickness in a hot press (table 5–14). The time in the pressure cylinder, therefore, can be approximated from the hot-press instructions for the particular glue being used by adding the pressing times given in table 5–14 to the time required to bring the pressure cylinder up to operating temperature. Heavy cast metal molds heat more slowly than sheet metal molds but the heat transfer will probably be more rapid than for wood. The rapidity of heating for any kind of mold depends largely on the heating medium (sec. 5.343).

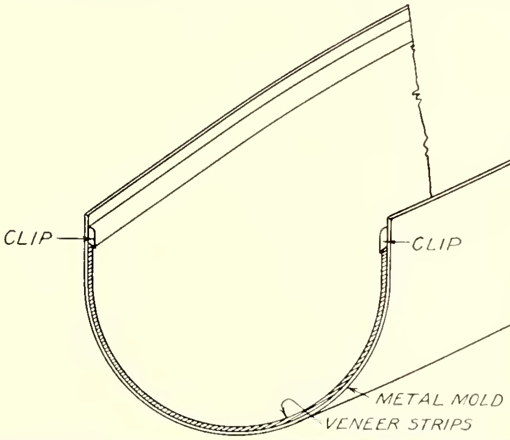


FIGURE 5–26.—Section through female metal mold illustrating clips for holding veneer strips in place.

Metal molds are very stable but those which are cast must be machined which makes them expensive and often difficult to obtain.

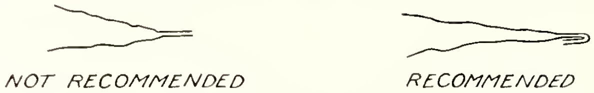
Molds in continuous use may require cooling before they can be used for the next lay-up. This is particularly true of small metal molds of considerable thickness, and on this type cooling is usually done with cold water. Large molded pieces require a longer time for removal; therefore the mold may be sufficiently cooled before it is again ready for use.

5.3202. Concrete Molds. If a concrete mold is used, a wood form must first be made to cast the concrete section. After this is done it is sometimes necessary to bond to the concrete a tacking surface of wood or possibly some other suitable material. Concrete molds have the advantage of being stable towards moisture but are excessively heavy and cumbersome to handle and are damaged somewhat by heat.

5.3203. Resins. Some attempts have been made to use casting resins, and other materials which can be poured, in mold construction, but to date these materials have been used mostly experimentally and have proved practicable in relatively few cases.

5.321. Bags or Blankets. The purpose of the bag is to provide a flexible impervious barrier between the fluid under pressure and the mold. The piece being molded is pressed between this flexible bag and the rigid surface of the mold and the full fluid pressure is applied at right angles to the surface of the bag regardless of the shape. The pressure at certain glue joints may be slightly less than the full fluid pressure by the amount necessary to shape the veneer or to force it into place.

Bags are classified as full bags or half bags (blankets). A full bag is a complete envelope of impervious flexible material (fig. 5–25, *A* and *C*) clamped shut at one end or side and having a connection, usually called a bleeder, to allow the entrapped air to escape to the atmosphere. It may be completely closed, similar in principle to a basketball bladder (fig. 5–25, *B* and *D*), having only a tube connection for inflation. A half bag, or blanket, is a sheet which normally fits the mold without wrinkling and is sealed by some temporary means to the edges of the mold (fig. 5–25, *E*). The bleeder may be attached to the mold or to the bag. Full bags are normally used over male molds and half bags are used on female molds.



A-FOLD CELLOPHANE OVER BEFORE SEALING EDGES

B-ARRANGE BAG ON FORM SO THAT SEALED EDGES ARE PLACED UNDER NO UNNECESSARY STRESS

C-ARRANGE SEALED EDGES SO THAT WATER CANNOT ACCUMULATE AT THE EDGE.

FIGURE 5–27.—Suggestions for sealing cellophane bags.

Because half bags do not support the weight of the mold, abrasive wear is less and their life greater than that of full bags. The use of fitted half bags is advised where production is high and they can be tightly sealed to the mold.

The useful life of a bag depends on the type of material used in the bag, the heating medium used, the temperature of the cycle, the size of the bag, and the care used in handling. It may be as short as 10 hours or as long as 200 hours of operation.

The type of bag to use and the material from which it is made depend largely on the molding process to be used, the temperature, and the heating medium. Most bag-molding operations at present require bags made of specially compounded natural or synthetic rubber, often reinforced with fabric.

Due to the present scarcity of all rubber materials, efforts are being made to find substitutes and means of increasing the production of molded plywood per pound of bag material used. In tests at the Forest Products Laboratory certain polyvinylidene chloride, vinyl butyral resin, and cellophane films have shown considerable promise as bag-molding materials. Their characteristics and use limitations are shown in table 5–16.

TABLE 5-16.—*Summary of materials tested at the Forest Products Laboratory as substitutes for rubber bag materials in making molded plywood*

Type	Recommended heating and pressure medium	Limitations of temperature	Life of bag	Notes on flexibility, toughness, etc.	Method of forming bag	Size of sheets available	Remarks
Regenerated cellulose single film.	Air (or inert gas)	Not critical	One cook	Will not stand rough handling.	Can be heat sealed	Continuous rolls up to 40″ width.	Air-tight but not so moisture proof as the next two types.
Regenerated cellulose laminated film.	Air, water, or steam.	Not critical	One cook	Will not stand rough handling.	Can be heat sealed	Continuous rolls up to 40″ width and prefabricated bags.	Steam passes through slightly but does not appear to be a serious disadvantage.
Thermoplastic polyvinylidene chloride film.	Air, water, or steam.	Not over 250° F. for 15–30 min.	One cook (perhaps more).	Very thin and very tough but becomes dry and brittle and easily damaged in removing from form.	Use in tube form, clamp both ends.	In tubular form. Largest at present is 24″ circumference.	Shrinks 10 percent in length and width when in use.
"Thermosetting" vinyl butyral resin between fabrics.	Air, water, or steam.	Not critical	Many cooks	Resistant to scuffing; pin holes developed in wrinkles after 450 min. at 320° F. (steam).	Cement edges with resin. "Vulcanize" or cure both material and seams in one operation.	Continuous rolls up to 36″ width.	"Double texture fabric" better than single fabric.

Half bags of cellophane[7] have been successfully used with a hot-air cycle on thin plywood shell molds. Joints between the cellophane sheets can either be made with cellophane tape on regular cellophane, or by overlapping the edges and applying a hot iron if the sheet material is of the self-sealing type. Several suggested methods for sealing cellophane bags are shown in figure 5–27. The life of a cellophane bag is limited to one operation.

The use of short-lived bag materials necessitates the frequent attachment of bleeder fittings. Figure 5–28 illustrates a convenient metal bleeder fitting that has been used satisfactorily with substitute bag materials.

Present information indicates that, in ordinary use on a steam-air cycle at temperatures of about 250° F., the life of a rubber bag is approximately 50 operations on a full unfitted bag. Repair of minor leaks, usually caused by rough handling, may be necessary during this period. The use of hot water or pure steam reduces oxidation and greatly increases the life of a bag. With a thick, fitted, half-bag assembly, considerably more than 100 operations may be expected in steam at 300° F.

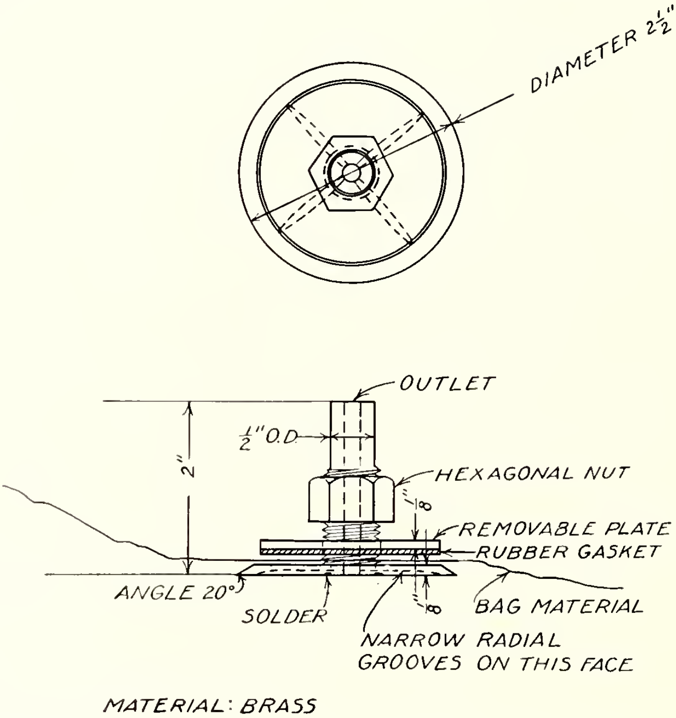


FIGURE 5–28.—Metal bleeder connection designed for rapid attachment to bags.

Whenever a steam-air mixture is used and the air is introduced under pressure from a compressor, an adequate after-cooler and air filter should be installed between the compressor and the cylinder. It has been reported that if all traces of oil, either in the form of small drops or of vapor, are removed from the air, the bag life is considerably increased.

Tests at the Forest Products Laboratory have indicated that synthetic rubber bags are generally more resistant to heat, both dry and wet, than natural rubber.

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[7] An application for a patent on the use of cellophane bags is reported to have been made by John S. Barnes, Skaneateles, N. Y.

In these tests also, a steam-air mixture at 250° F. was found more damaging to all bag materials of rubber or synthetic rubber than pure steam at 300° F. or even 320° F. Where conditions permit a choice between these two heating mediums, it is advisable to use pure steam at 300° F. (52 pounds per square inch) to gain the advantage of a longer bag life and a shorter heating cycle.

Normal rubber bag thicknesses are between one-thirty-second and one-eighth inch, depending upon the amount of reinforcing, the severity of handling, and the type of bag molding. The thinnest bag capable of withstanding the handling and mechanical wear is recommended. A thin bag has several advantages: probably most important is its more rapid heat transfer. By using thin bags, more molded plywood is turned out per pound of bag, provided the bag is strong enough to withstand the handling. When thin bags are used, wrinkles in the bag are less likely to leave their marks on the bag side of the piece being molded. This is important with thin veneers, since a thick bag could easily produce an area of poor glue joint, as much as one-fourth inch wide and several inches long, as a result of reduced pressure under a fold. A practical guide, whenever bag wrinkles are likely to occur, is to use a bag slightly thinner than the face veneer.

In all bag molding it is advisable to use a layer or two of paper, cloth, or canvas between the plywood being molded and the bag. This facilitates the "bleeding" of air and steam to the outside. It also prevents adherence of the glue squeeze-out to the bag. It is advisable to cover any sharp corners at the edges of the molded plywood piece with extra layers of canvas to prevent injury to the bag.

Whenever a rubber bleeder hose is used, as in figure 5–25, *C* or *E*, it must not collapse and close when external pressure is exerted upon it during the molding cycle, if it is to fulfill its purpose. Collapse is difficult to observe due to the fact that, while the tube is collapsed, it is within the cylinder and not visible unless the cylinder has a glass observation window. Emission of a slight amount of air or steam from the bleeder does not guarantee that it is functioning properly. A flexible metal hose or a suitably reinforced rubber hose is recommended for the bleeder wherever this type of hose gives the necessary flexibility.

In using the methods shown in figure 5–25, *A* and *C*, careful attention should be given the inside surface of the bleeder fitting in the bag. If this is very smooth and flat, it may make an almost airtight fit and stop the bleeder from functioning. Grooves in this fitting as shown in figure 5–28 or a piece of coarse burlap glued to it, will usually suffice.

5.322. Pressure and Temperature Equipment. All pressure cylinders for use with bag molding should be hydraulically tested to a pressure of at least double the maximum working pressure used. An adequate safety valve should always be installed if the boiler or compressor pressure is in excess of the pressure at which the cylinder was tested.

The sensitive elements placed within the pressure cylinder for controlling and recording conditions should be carefully installed. Heavily jacketed controls will be sluggish and therefore will not record the actual cylinder temperature during the rapid heating-up period. A jacketed thermometer was found in experiments at the Forest Products Laboratory to be about 20° to 30° F. below the reading on a bare thermocouple in heating a cylinder 2 feet in diameter and 6 feet long to 250° F. in 5 minutes, using a steam-air mixture.

If temperature stratification exists in the cylinder, a temperature-recording bulb at the top of the cylinder may be 30° F. or more above the actual temperature at the bottom of the cylinder; provision for circulation should therefore always be made if possible. A good check on uniformity of temperature may be had by inserting bare thermocouples in the top and bottom of the cylinder.

A large inlet for the heating medium is advisable, so that the cylinder can be brought up to the desired temperature and pressure in 5 minutes or less. Usually this rapid heating is advisable, which on large cylinders will mean high boiler and compressor capacity.

5.33. Glues for Bag Molding. A list of current synthetic-resin glues with a tabulation of their principal characteristics, as related to use requirements, is given in table 4–1. Those that have been reported in successful use and that have been used satisfactorily in limited bag-molding experiments at the Forest Products Laboratory, with proper adjustment of heating cycle and other operating conditions, are indicated by a footnote reference. In selecting a glue and using it in bag-molding operations, however, close cooperation is urged between the user and the glue supplier to insure best results. The selection of glues for bag molding aircraft parts is limited by the requirements of the current aircraft specification on molded plywood.

Parts to which bag molding is best adapted are either large or of severe double curvature or both and a long period (varying perhaps from 1 to over 10 hours) is required to adjust the strips of veneer in place on or in the mold. During this period, a small amount of hand fitting with a plane or sandpaper block is usually necessary. These conditions require the use of a glue that is dry at the time of assembling and that permits a long assembly period. A satisfactory bag-molding glue should have an allowable assembly period of at least 30 hours to be adapted to bag-molding operations in general.

It has been suggested previously that the cylinder temperature and pressure be brought up to operating conditions in 5 minutes or less (sec. 5.322), but in some cases, particularly where large cylinders are used, this is impossible to accomplish with the available boiler and compressor capacity. Under such conditions there is danger with some glues of pre-curing the outer glue lines before sufficient pressure is applied. The relation between the characteristics of the glue and the rate of pressure and temperature rise is critical and should be examined carefully.

It is desirable in all bag molding of double-curvature parts with thermosetting glues to use a glue that passes through the fluid stage relatively slowly and while in this stage has a high degree of flow. This produces the effect of a lubricant between the adjacent plies of veneer and allows them to slip to their proper place, thus often avoiding wrinkles. Most of the glues in table 4–1 that are designated as bag molding glues have this property. Additional information on the slipping properties of these glues is given in reference 5–27 of section 5.35.

In addition to the characteristics described above, it is important that glues for bag molding, in common with other aircraft uses, remain durable under service conditions. The properties of various types of glues have been described under section 4.1. The phenolics and certain modified phenolics, fortified ureas, and thermoplastics meet bag-molding requirements reasonably well but vary in their resistance to severe exposure conditions. Current thermoplastic glues, which are otherwise well adapted to bag-molding processes, give evidence of slow flow at elevated temperatures, such as 150° to 160° F., and should not be used in aircraft parts. They are, however, often used in experimental work, particularly on the first few pieces and made on a mold having curvatures likely to cause trouble. They have a high degree of flow when plasticized by the heat in the molding cycle and if a wrinkle is formed in the molded part it can often be removed by a subsequent reheating.

5.34. Bag-molding Technique.

5.340. Size, Shape, Thickness, etc. In applying bag-molding technique it is necessary to study carefully the piece to be produced. This means a consideration of curvatures, the approximate thickness and number of plies, species, and arrangement of alternate plies. The curvature of the piece may determine the thickness of the veneers that can be used. Table 5–17 will serve as a guide to the approximate relation between the thickness of veneer and the minimum radius of curvature considered practical in bag molding. These ratios are only suggested minimums; the actual permissible minimums will vary with the species, the moisture content of the veneer, and the method of veneer cutting. The method of holding the veneer in place on the mold is usually the determining factor; therefore, it will be noted that the suggested ratios are well above those at which the veneer may be expected to break. Breaking radii are discussed in section 5.6830.

TABLE 5–17.—*Approximate minimum ratio of radius of curvature to thickness of dry veneer for bag molding*

Angle between direction of grain and axis of curvature	$\text{Ratio} = \frac{\text{Radius of curvature}^{1}}{\text{Thickness of veneer}}$
90	100 to 1
0	50 to 1

[1] As measured in the plane perpendicular to the axis of curvature. A few tests made on strips of plywood at 45° indicated that there was little or no difference between results obtained at 0° and 45°.

5.341. Moisture Content. A moisture content of 8 to 12 percent in veneer used for bag molding is favorable and within this range any variations depend mainly on the glue being used. Variation in moisture content between the veneer sheets in any one assembly should not, however, exceed 2 percent. Change in moisture content during manufacture is often serious, since the veneer strips are cut to exact shape. If the width of the strips changes in the period between shaping and assembly considerable hand fitting will be required. The importance of dimensional stability depends on the shape and size of the molded part, but in extreme cases on larger parts some plants have found it advisable to control the relative humidity within ± 2 percent in the lay-up room and the rooms where veneer is stored. On other smaller parts or on parts made from narrow strips of veneer no control of moisture content, other than that required for the glue, is attempted.

The bag-molding operation does not greatly change the moisture content of the veneer, unless leaks develop in the bag. Tests on small flat pieces indicate that the moisture loss during molding is less with wood molds than with metal molds. It is also less in both types of molds when no vacuum is maintained on the bag. Preliminary tests made on plywood molded in bags of suitable grades of cellophane indicate little or no change in moisture content of the veneer during the molding cycle. In all the tests the moisture loss was considerably less in bag-molding than in hot-press operations on the same combination of species and glue.

5.342. Assembling the Veneer. The degree of double curvature will determine the width of the individual strips of veneer. Naturally it is more economical of labor to use a few wide strips instead of many narrow ones, in order to reduce the number of necessary shaping operations to a minimum. On the other hand, if the strips are too wide, their edges will wrinkle as the fluid pressure on the bag presses the flat strips against the double-curved mold. On double-curvature molds, such as required for fuselages or bomber noses, the strips are usually between 2 and 8 inches wide.

The strips of veneer must be tapered or "tailored" very carefully to fit the mold so that a close joint is obtained between the adjacent strips (fig. 5–29). To determine the exact shape of each strip the first lay-up is carefully done by hand and later disassembled, each strip being marked to designate its position on the mold. In production, this tailoring is usually done by first sawing the strips roughly to shape

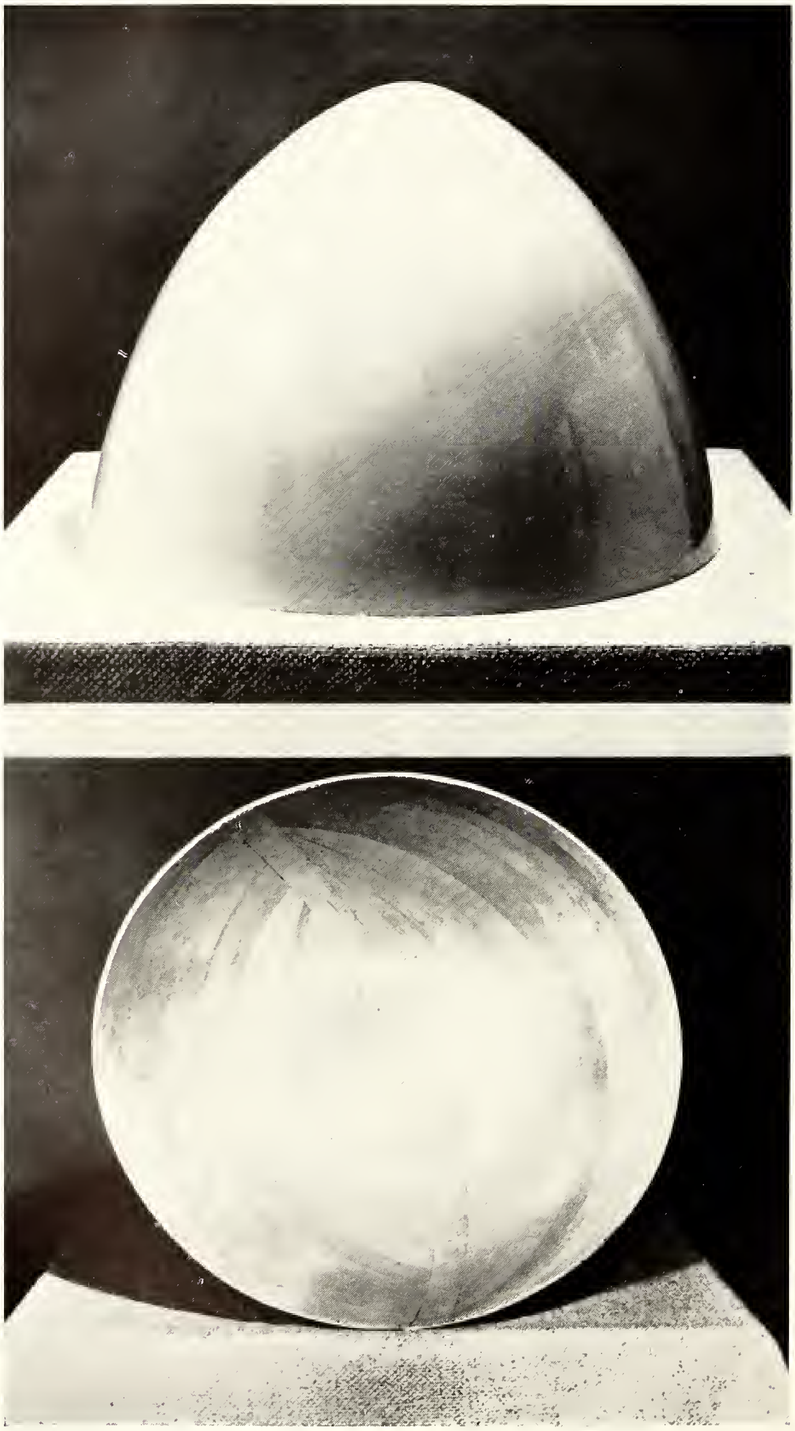

FIGURE 5-29.—Typical airplane spinner of molded plywood. (*Above*) Exterior view; (*below*) interior view showing tailoring of strips.

and then shaping them exactly on a vertical spindle shaper, using plywood or metal templates, each accommodating a stack of veneer strips approximately 2 inches high.

Sometimes the pieces are sawed to final shape and then each edge is run through a special scarfing or feathering device consisting of a small sandpaper-lined drum and a hold-down. The strips are then spread with glue and laid on the mold so that the edges overlap one-fourth to one-half inch, depending upon the veneer thickness. As the veneer strips are assembled on the mold, they must be fastened or held in place. Fastening of veneer to metal molds is illustrated in figure 5–26. On wood molds this fastening is conveniently done by means of staples or tacks. The first layer of veneer is stapled directly to the wood mold and, as each successive layer is applied, the staples in the preceding one are removed. By this procedure the finished molded piece (fig. 5–30) has no staples in it since those in the outer layer are removed after curing.

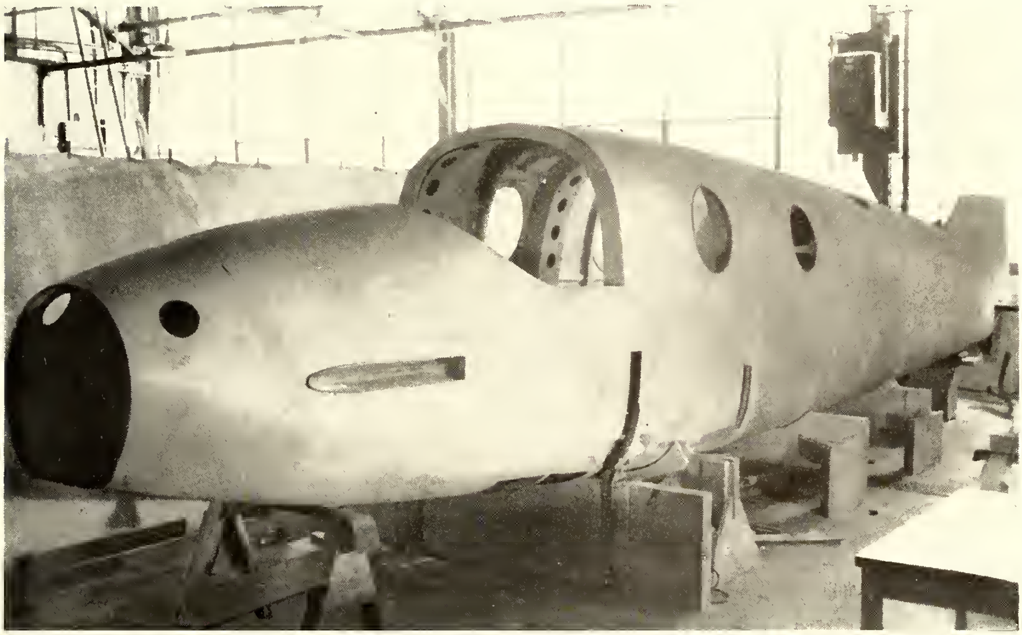

FIGURE 5–30.—A training bomber fuselage molded on a wood mold by means of laying up veneer strips.

The same principles of balanced construction that apply to flat plywood are applicable to molded plywood. For maximum resistance to warping all plywood should be symmetrical about the center plane of thickness. In this connection symmetry involves species, number of plies, thickness of plies, and direction of grain. In theory, a symmetrically constructed panel with alternate plies laid at 90°, with respect to direction of grain, would have maximum dimensional stability. In practice, however, a construction with alternate plies at 90° to each other is often impossible in pieces of pronounced compound curvature.

5.343. Heating Mediums. Heating mediums in current use are steam, steam-air mixtures, water, and air.

Pure steam is often used when high temperatures are desired. In this cycle an exhaust valve is left partly open for a short period after the steam valve is opened so that the residual air is expelled.

The steam-air mixture usually requires an air compressor in addition to a steam boiler. Some so-called steam cycles are in effect steam-air cycles as the cylinder is sealed and charged with steam without discharging the residual air. Under these conditions the pressure and temperature of the charge will not agree with temperature-pressure tables for pure saturated steam.

The use of hot water requires an auxiliary storage tank in which the water is heated and to which it is returned after use in the heating cycle. This tank is often mounted above the molding cylinder so that the hot water can be introduced rapidly by gravity through a large pipe. It is returned by means of a centrifugal pump. The pressure for the molding operation is applied by air.

When air is used as a pressure and heating medium, heating is done by means of a steam jacket around the cylinder. Additional heat is sometimes supplied by steam coils within the cylinder or possibly by electric strip heaters. Extreme caution should be exercised when using electric heaters or any electric connection, as the combination of compressed hot air, combustible material, and a glowing heater within a cylinder is very dangerous.

Each heating medium has certain practical limits of temperature. An attempt has been made at the Forest Products Laboratory to determine these limits from actual heating tests in which thermocouples were inserted in the cylinder and at various depths in a piece being molded on a wood mold to record the rise in temperature. These limits as well as other practical limitations of 11 different techniques which have been or could be used in bag-molding plywood are presented in table 5–18.

5.3430. Notes Referring to Table 5–18.

1. Natural and synthetic rubber give highest production bag life with pure steam; some grades of cellophane are usable for one cycle. Pressure is too low for general bag gluing below 260° F. (20 pounds per square inch at 260° F.); above 320° F. there is danger of overcuring the outer glue joint and bag deterioration is very rapid.
2. Steam-air is more damaging to rubber than steam or hot water; some grades of cellophane are usable for one cycle. Circulation to avoid stratification is required, especially below 240° F.; severe oxidation of bag materials occurs above 280° F.
3. Long bag life can be expected from hot water cycle as there is no oxidation; some grades of cellophane are usable for one cycle. Open-storage tank may be used below 212° F.; above 300° F. pure steam can ordinarily be used to advantage since the water must be kept under the same pressure as is required for steam.
4. This is a very slow cycle due to low specific heat of air. Seventy-five pounds per square inch is suggested as maximum safe pressure.
5. Carbon dioxide, nitrogen, or any other gas which will not support combustion or affect bag materials may be used.
6. Mold is heated, and unheated air is used for pressure; therefore bag stays relatively cool throughout cycle.
7. Same as 6, except that inert gas is recommended to avoid danger of explosion in case of spark or a short circuit in wiring system.
8. Bag is expanded against work by means of steam. An adequate drain for condensate is required at the lowest spot in the bag.
9. Same as 8, except that steam-air mixture is used. See note 2.
10. Steam-heated mold is used; bag inflated by air pressure, therefore no drain connection necessary for bag.
11. Same as 10 except that mold is heated electrically; inert gas is recommended for safety, although air may be used in some cases.

TABLE 5-18.—*Equipment and limitations on conditions in various methods of bag-molding plywood*

Table reference note number (see Sec. 5.3430)	Illustrated in:	Major equipment required	Pressure medium	Source of heat	Practical bag materials	Practical limits of temperature	Practical limits of pressure	Mold material
		Autoclave Molding			*Class* [1]	°*F.*	*Pounds per square inch*	
1	Figure 5-25, C and E.	Autoclave, boiler	Steam	Steam	1	260–320	20 to 80	Wood, metal, plastic or cement.
2	do	Autoclave, boiler, air compressor	Steam-air	do	1	240–280	20 to SWP [2]	Do.
3	do	Autoclave, boiler, pump, heater, tank, air compressor.	Air	Water	1 or 3	to 300	20 to SWP [2]	Do.
4	do	Autoclave, boiler, fan, air compressor	do	Steam coils	2 or 3	to 300	20 to 75	Do.
5	do	Autoclave, electric heaters, fan, compressor, gas supply.	Inert gas	Radiation and convection through inert gas.	1 or 2	to 320	20 to SWP [2]	Do.
6	do	Autoclave, boiler, air compressor	Air	Steam-heated mold	1, 2, or 3	to 320	20 to SWP [2]	Metal, plastic or cement.
7	do	Autoclave, compressor, gas supply	Inert gas	Electrically heated mold.	1, 2, or 3	to 320	20 to SWP [2]	Do.
		Pressure-mold [3] *Molding*						
8	Figure 5-25, B and D.	Pressure mold, boiler	Steam	Steam	1	260–320	20 to SWP [2]	Wood, metal, plastic or cement.
9	do	Pressure mold, boiler, air compressor	Steam-air	do	1	240–280	20 to SWP [2]	Do.
10	do	Steam-heated pressure mold, boiler, air compressor.	Air	do	1, 2, or 3	to 320	20 to SWP [2]	Metal or cement.
11	do	Electrically heated pressure mold, compressor, gas supply.	Inert gas or air	Electricity	1, 2, or 3	to 320	20 to SWP [2]	Metal or plastic.

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[1] Class 1—Steam-, water-, and air-tight at temperatures up to 320° F. Natural and synthetic rubber and some grades of cellophane.
Class 2—Air-tight and usable up to a temperature of 320° F.—cellophane.
Class 3—Air- or liquid-tight up to a temperature of 212° F.—rubber, cellophane, resin-coated cloth, and thermoplastic films.

[2] SWP equals the safe working pressure of the apparatus being used, which is determined by the type and condition of the apparatus and State safety code requirements.

[3] A mold that will withstand internal fluid pressure.

Hot air, besides being a very poor heating medium, produces results very largely dependent upon the amount of circulation in the cylinder. It is also difficult to determine separately the effect of radiation from the hot-jacketed cylinder walls or heater and the effect of convection. There is considerable interest of late, however, in the use of air, for two reasons: first, leaks developing in bags do not damage the piece and the mold, as is likely with the steam or hot-water cycle; and, second, a few of the bag materials suggested as substitutes for rubber are not steam- or hot-water proof but are better adapted for use with air or some inert gas.

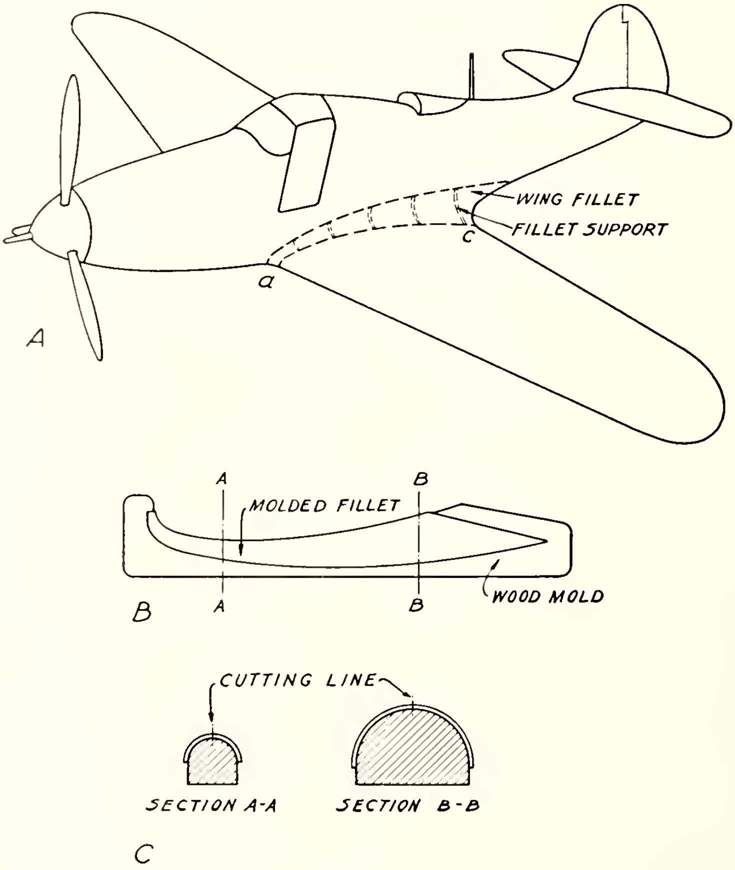

Figure 5-31.—Suggested method of molding wing fillets.

The use of air under high pressure and temperature conditions is exceedingly dangerous, and all known safety precautions and regulations should be observed. The compressor should always be equipped with an adequate aftercooler and oil-vapor filter. The lubricating oil in the compressor should have a high flash point so that a minimum of vapor is given off. All precautions should be taken to eliminate any sparks in a cylinder charged with hot air containing some oil vapor, as a dangerous explosion can result.

5.344. Amount of Pressure. The pressures used in bag molding vary from a vacuum drawn on the bag to a maximum of about 120 pounds gage pressure per square inch. The bulk of the current bag molding is done at from 40 to 80 pounds per square inch. Vacuum alone produces insufficient pressure for most bag-molding operations and therefore is not recommended for aircraft plywood.

5.345. Heating Cycle. The selection of a proper heating cycle to cure the glue and bond the veneer into the finished molded part is complicated by the fact that the synthetic resins do not have a definite temperature at which polymerization, or condensation, occurs. If a clearly defined temperature were required for the polymerization of any one adhesive, the proper heating cycle could be calculated (making certain assumptions and allowances for end heating, moisture content of the wood and mold, diffusivity of the bag materials, etc.) at any desired bag temperature. Polymerization of any synthetic resin of the thermosetting type, however, is influenced by both temperature and time of heating; therefore, any calculation of the temperature that exists at a given glue line within a structure is directly applicable only when the time-temperature conditions required to produce a good bond with the glue in use are known.

As an example, a phenolic-resin film is reported to be completely cured in about one-half minute at 350° F. but requires about 10 minutes at 275° F. This suggests the development of temperature-time relationship factors for calculating the time required to cure completely each of the common synthetic-resin glues (*5–23*), but until some more satisfactory method is presented, the heating cycle can only be determined empirically. Table 4–1 does, however, indicate the suggested cylinder temperature to use for best results on some of the glues suitable for bag molding.

The rate of heating of the veneer assembly on the mold also affects the length of the heating cycle selected. A difference in the rate of heating on thin metal molds as compared with thick wood molds has been indicated (sec. 5.3200).

Maintaining uniform temperature in the cylinder throughout the cycle and avoiding stratification of the heating medium by means of adequate circulation in the cylinder are necessary to secure uniform rates of heating.

Under any particular set of operating conditions, an occasional check of the actual temperature at the coolest glue line throughout the heating cycle is desirable. A satisfactory method of making this check is to use fine thermocouples, leads, and a potentiometer. Copper and constantan leads of No. 30 gage have been found satisfactory, and they may be embedded in the molded part without danger of injuring trimming equipment.

Approximate temperature checks have also been made in some cases by the use of temperature-sensitive crayons or paints. The final check, of course, is the ability of the glue joints in the finished product to meet specification requirements.

5.346. An Example of the Bag-molding of a Specific Product. Assume that it is desired to bag mold the wing fillets of a plane such as shown in outline form in figure 5–31, A.

Lacking definite information such as drawings and specifications, certain assumptions will have to be made. This is probably an unstressed part and merely acts as a smooth, rounded fillet between the fuselage and upper wing surface to reduce turbulence in the air flow. It will also be assumed that the minimum radius of curvature is about 3 inches and that, when viewed from the top, the line *ac* is approximately straight.

(1) Use requirements:

Nonstressed—but scuffing, air action, and weather resistance demand at least 3/32-inch thickness of hardwood.

Suggested construction: 1/32-inch rotary-cut yellow birch faces, 1/24-inch rotary-cut yellowpoplar core. Glue will be spread on both sides of core strips only. Strips of veneer laid at a +45° and −45° angle with the junction between the fairing and the fuselage. For additional abrasion resistance (if necessary) both faces may be precured resin-impregnated birch.

(2) Moisture resistance:

Severe conditions, use hot-press, phenolic-resin glue or equivalent as provided in current specification covering molded plywood for aircraft parts.

(3) Degree of curvature:

Width of strips to be determined by trial. Minimum radius of curvature is 3 inches, thus $\frac{3.00}{50}=0.060$-inch probable maximum thickness of veneer. One thirty-second-inch yellow birch and $\frac{1}{24}$-inch yellowpoplar should bend nicely.

(4) The mold: Examination of the shape in figure 5–31, *A*, reveals that if it is turned upside down and its mate from the right side placed beside it so that the line *ac* on each coincides, the pair can be molded in one operation as a single unit on a saddle-shaped male mold (fig. 5–31, *B*). Later the unit can be divided into two parts.

By this selection, the side next to the mold, which will be the smoother side, is the side later exposed to the air stream.

A wood mold will be used, probably built up of resin-bonded plywood laid flat and glued together. After shaping the mold, an impregnated birch skin of three plies of $\frac{1}{32}$-inch veneer will be bonded to it to provide a smooth tacking surface.

The method shown in figure 5–25, *C*, will be used, as it is perhaps best suited to this shape of mold.

(5) The bag: A full, reinforced synthetic-rubber bag $\frac{1}{32}$-inch thick will be used over a wrapping of paper or cloth. The bag will not be formed, but will be generously large, so that stretching is unnecessary. A vacuum will be drawn on the bag after the mold is inserted, to check for leaks and to inspect the folds in the bag. This vacuum will be maintained until the cylinder pressure is applied, to avoid any shifting of the bag and reforming of bag wrinkles.

After the cylinder is sealed, air pressure of approximately 15 pounds per square inch will be applied; then the temperature and pressure will be adjusted by the admission of pure steam and venting to obtain a temperature of 300° F. and a pressure of 52 pounds per square inch within a period of 5 minutes or less.

(6) Heating cycle: The mold is small and contains no large flat spots, therefore the temperature rise at all points will be somewhat more rapid than usual.

Using a high-temperature phenolic glue and a cylinder temperature of 300° F., a satisfactory cure should be obtained in a total of 15 minutes.

5.347. Suggestions on Bag-molding Technique. One type of curved part, which requires special attention in production, is the U-shaped cross section (two essentially flat and parallel sides connected by a curve of small radius). Examples of this shape are the leading edges of wings and of vertical stabilizers. When attempting to make these U-shaped pieces on a male mold, wrinkles often result at the point of greatest curvature. Regardless of how tightly the veneer is wrapped by hand and attached to the mold, the fluid pressure will tend to press it more firmly to the mold. Since fluid pressure is exerted at right angles to the surface, the total force exerted on the sides is greater than that exerted on the end. The force on the end tending to overcome the frictional resistance under the sides causes a wrinkle to be formed in the curved part.

Several special techniques have been developed for eliminating these wrinkles, one[8] of which is illustrated in figure 5–32. For simplicity, a single curved piece having parallel flat sides 8 inches long connected by a curve of 2-inch radius is illustrated.

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[8] It is reported that a patent application on a somewhat similar technique has been made by the Vidal Research Corporation.

Triangular strips ¾-inch high are attached to the mold about 2 inches beyond the end of the piece being molded. The relation between these dimensions has been found to be important in obtaining good results. A piece of heavy canvas, or any other strong, flexible, nonelastic material, is tacked or otherwise attached to the mold at *A* after being tightly wrapped around the assembly. The whole assembly is then put in a thin, reinforced, full bag and pressure and heat applied, as illustrated in figure 5–25, *C*. As the fluid pressure is applied, the canvas puts additional force on the curved portion and at the same time prevents full force from being exerted on the flat surfaces. As full pressure is reached, the canvas has assumed the position shown in the dotted lines and full fluid pressure is then applied to the flat surfaces, while the curved portion has full fluid pressure plus the additional pressure from the tension in the canvas.

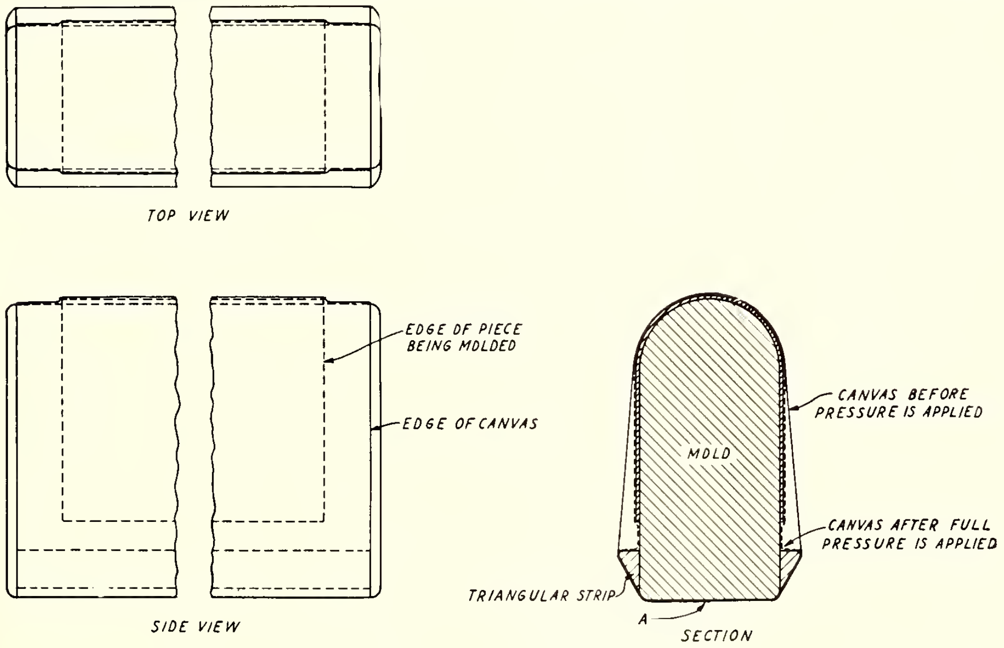

FIGURE 5–32.—A method for molding U-shaped sections.

Removal of most if not all the staples attaching the flat sides to the mold before pressing facilitates the slipping of these sides and it is reported that, in some cases, the use of the triangular strips is then unnecessary.

5.3470. Tubular Members. Tubular members of molded plywood are also difficult to mold, although here again only single curvature exists. The cross section of these parts may be circular, elliptical, or any other closed shape. Figure 5–33 shows a short section of a cylindrical member such as is sometimes used for air ducts. These members have been bag molded by several methods, usually involving the use of accurate metal molds. The fundamental problem is the same in all; namely, to secure a very close fit between the veneer strips or sheets and the mold. If this is not accomplished, the fluid pressure will produce defects as it forces the veneer tightly against the mold.

In tubular members, as in compound-curvature pieces, a +45° and −45° angle of grain to axis of curvature causes the least difficulty in assembly. A sheet of veneer in width 2.22 times the diameter of the cylinder, wound helically around the mold so that the opposite edges touch, will produce an angle of 45° between its edges and the axis. Successive strips wound in opposite rotation make a construction having a 90° angle between alternate plies. Butt joints parallel to the grain are usually made between adjacent strips. On long cylinders it is necessary to scarf joint and glue the strips end to end to secure the required length of material.

A common method of making these cylindrical members is to wrap the strips around a thin metal cylindrical mold, taping them in position. The bag is also tubular but somewhat larger than the mold so that it may be slipped over the assembly and clamped to the mold near each end. The bleeder may be attached to either the mold or the bag.

The process is sometimes reversed and the veneers assembled within the cylindrical mold. In this process the bag is inserted inside the mold and inflated to produce pressure, a process somewhat similar to figure 5–25, *B* and *D*.

FIGURE 5–33.—Short section of tubular-molded plywood.

If it is necessary to use the 0° to 90° assembly of veneers, the 90° material (grain around the bend) should be scarfed at the ends. In long tubular members it may also be necessary to make scarf joints in the 0° material.

In all tubular work the veneer sheets must be very flat and plate redrying before laying-up is often necessary. Any cupping of veneer caused by glues containing water must be avoided; therefore, an alcohol-soluble glue or a dry-sheet glue is generally used.

5.3471. Bag Leaks. Obviously, all precautions should be taken to avoid the occurrence of leaks in the bags used in bag molding. In spite of this, leaks will occasionally occur on account of the natural deterioration of the bag material. How long a bag can be used before it must be discarded is a question that can only be answered by balancing the cost of repairing leaks and the value of molded parts ruined by the leaks against the cost of a new bag. As an aid in arriving at the answer, it is suggested that a record be kept of the performance of each bag or type of bag. A summary of these records will indicate the optimum point at which the bag should be discarded, and will also show which type of bag is giving the best service.

Conditions other than material deterioration that cause early bag failure are, in nearly all cases, traceable to improper handling. The actual leak is usually caused by any one of the following and may be accelerated by slight deterioration of the material:

1. Tear due to rough handling.
2. Hole from abrasion due to sliding of a heavy mold on the bag.
3. Rupture of bag from concentrated load.
4. Rupture of bag by fluid pressure over unsupported area.
5. Tear caused by shrinkage of reinforcing fabric, due in turn to seepage of water through outer coating of rubber, allowing fabric to get wet.
6. Improper sealing of the bag.

Some bag leaks develop during the heating cycle, and when the leak occurs after the glue has set the molded part may often be salvaged. It should, however, be carefully inspected to determine whether the glue bond is satisfactory. Parts which are only partially wet are sometimes thoroughly soaked and dried to remove local distortions. This treatment also reveals the presence of poor glue bonds.

Any bag that has shown evidence of leaks should immediately be removed from production and examined. This is often done by inflating the bag and painting it with a soap solution. The leak will be revealed by bubbling of the soap film.

5.35. Bag-molded Plywood References.

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5.4. GLUING AND ASSEMBLY OPERATIONS.

5.40. General. Current practices in the fabrication of wood aircraft parts and their assembly into the finished plane are by no means standardized in the industry, and many departures from or variations of the procedures set forth herein are to be found. Most of the processes described, however, have been observed in actual commercial practice. In each of the assembly gluing operations discussed, the various methods and practices described are believed to conform reasonably closely to the detailed recommendations given in section 5.2. The following gluing conditions and limitations apply generally to all assembly gluing operations and should be followed, unless otherwise specifically excepted under the description of each operation.

5.400. Moisture Content of Wood. Wood pieces, parts, and subassemblies should have a moisture content of between 8 and 12 percent for assembly gluing operations, except for special constructions made from thin plies or laminations by cold-press gluing. Because of the moisture added by cold-setting glues when used with thin material, a moisture content of 5 to 8 percent is recommended if the stock is one-eighth inch or less in thickness (sec. 5.20). Within either range of moisture content recommended, the members in any one assembly should not vary by more than 2 percent in moisture content.

5.401. Preparation of Gluing Surfaces. After the stock has been conditioned to the required moisture content, and immediately before gluing, all surfaces should be machined smooth and true and accurately fitted as discussed in sections 5.21 and 5.6. An interval of more than 8 hours between final surfacing and gluing is undesirable. Specification AN–P–15a requires a lapse not to exceed 4 hours between surfacing and gluing.

5.402. Preparation of Glue for Use. Manufacturers' recommendations should be followed for mixing glues. The proportion of all ingredients shall be determined be weight. Glues should be thoroughly mixed to an easily spreadable consistency and mixtures that become difficult to spread should be discarded. Colored paper cups are being used for dispensing cold-setting glues as an aid in assuring that the glue used is fresh and of satisfactory consistency. For example, if the glue is mixed twice daily, the morning mix may be placed in green cups and the afternoon mix placed in red cups; all glue used in the morning would thus be from green cups and all used in the afternoon from red cups.

5.403. Glue Spread. The glue mixture should be applied uniformly to either or both of the surfaces being joined (sec. 5.23). Double spreading is recommended for the gluing of scarf joints or when certain unfavorable gluing conditions, such as long assembly periods or rough wood surfaces, are encountered. Under these conditions, the total amount of glue applied should be increased about 25 percent (sec. 5.23).

5.404. Assembly Periods. When gluing conditions permit closed assembly and application of adequate gluing pressure, the assembly time should not exceed 20 minutes with cold-setting glues. Open assembly periods should not exceed 10 minutes at temperatures of 70° to 90° F. When pressures of less than 75 pounds per square inch are used, as in nail gluing, closed and open assembly periods should not exceed 15 and 8 minutes, respectively (sec. 5.24 and table 5–12).

5.405. Gluing Pressures. The amount of pressure needed for satisfactory gluing depends to a large extent upon the uniformity of its application. When applied between rigid surfaces, as when stiff cauls are used to distribute the pressure uniformly, gluing pressures of 100 to 250 pounds per square inch, depending on the density and crushing resistance of the species, are recommended (sec. 5.25). When gluing high-density species to those of low density, the recommendations for the low-density species govern the maximum gluing pressure that should be applied. Nail gluing is always associated with relatively low and undetermined pressures.

Nail gluing should be limited to thin members, as when plywood skins which deform readily under small pressures are glued to supporting structures. It is considered questionable to use nails to apply gluing pressure if the thinnest member exceeds one-eighth inch in thickness and nail gluing should not be used if the thinnest member exceeds one-fourth inch in thickness. When fluid pressure is applied directly against the part being assembled, somewhat lower pressures are permissible because the pressures are uniform and are applied at right angles to the surface. The structural strength of the assembly will often limit the maximum pressure, but within these limitations the nearest practical approach to the recommended pressures should be used.

5.406. Pressure Period. Stock glued with cold-setting glues should remain under pressure at least 4 hours at 70° F. or 2 hours at 90° F., but a longer pressing period is desirable (sec. 5.262). Cold-setting, urea-resin glues should not be used on wood or in a room that is below 70° F. At elevated temperatures the pressing period can be appreciably shortened for assemblies glued with either the cold-setting, urea-resin or casein glues (sec. 5.263).

5.407. Conditioning Period. Following the gluing operation, the stock should be conditioned for a sufficient time to ensure the development of the full strength of the joint and to permit the moisture added by the glue to be removed or distributed throughout the wood. The type and duration of the conditioning treatment needed are considered under specific gluing operations (sec. 5.28).

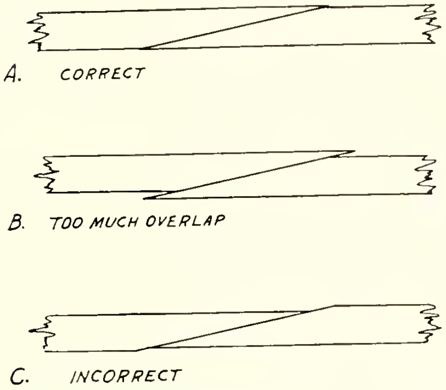

FIGURE 5-34.—(A) Correct, (B) acceptable but wasteful, and (C) incorrect methods of aligning scarf joints for gluing.

5.41. Gluing of Scarf Joints. The requirements of scarfed surfaces for gluing and the methods used in producing them are described under sections 2.4 and 5.6.

5.410. Scarf Joints in Solid Stock. After the surface has been prepared with the required slope, the gluing operation itself should follow the fundamental principles discussed earlier, with one or two additional precautions.

5.4100. Prevention of Slippage. In the gluing of scarf joints, probably the most important single consideration is to prevent end slippage. Effort should be made to keep the parts in proper alignment, as illustrated by figure 5–34, *A*. A small amount of overlap as illustrated is desirable and insures that the joint will receive adequate pressure. If the members slip excessively endwise during the pressing operation, a condition will exist as illustrated in figure 5–34, *C*. When the members are in this position, the joint will not receive sufficient and uniform pressure, and erratic joint strengths may be expected. The condition illustrated by figure 5–34, *B*, is to be preferred to *C*. In case the members are in a position illustrated by figure 5–34, *B*, it is possible that the scarf joint will receive higher pressure than intended and some crushing may result, but very probably the quality of the glue joint will not be adversely affected. It is important to provide some method, such as blocking or clamping the ends of the members, to prevent end slippage. Blocking or clamping should also be arranged to minimize side slippage and thus prevent unnecessary waste of material. Wood pins of small diameter driven into drilled holes are sometimes used to prevent end and side slippage. These pins have an advantage over nails, sometimes used for the same purpose, in that they can be left in and do not interfere with subsequent machining operations.

5.4101. Glues. In gluing scarf joints with cold-setting glues, it is recommended that the glue mixtures contain about 10 percent less water than is normal for side-grain gluing. Both contact surfaces should be coated and the maximum pressures permitted by the species should be used. For the dense, porous hardwoods, particularly when the maximum permissible slope is approached, sizing of the scarfed surfaces with a thin glue mixture prior to gluing is helpful in preventing excessive penetration (sec. 5.271).

In thick stock, the choice of glues is usually limited by operating considerations to cold-setting, urea resins, or casein glues (sec. 4.2). If the stock is thin, hot-setting, synthetic-resin glues may be used, provided heat can be applied to set the glue. Where satisfactory electrostatic heating equipment is available, hot-setting resins can be used on thick stock as well as on thin stock (sec. 5.264).

5.4102. Gluing Operation. In the gluing operation, proper control of the fundamental gluing factors described in chapter 4 and section 5.40 should be observed. After removal from the press, stock of different thicknesses should be conditioned for 3 to 7 days at ordinary room conditions or for 1 to 3 days in a kiln or room at 100° to 120° F., with humidity controlled to maintain the moisture content of the stock within the range of 8 to 12 percent (sec. 5.28).

Pressure can be exerted by any mechanism that will apply a load of the desired magnitude uniformily over the joint area. Screw presses of conventional design are frequently used (fig. 5–35). The number of scarf joints pressed simultaneously in the same device should be limited in order that alignment may be maintained and an even distribution of pressure insured.

If the members are thin and the operation is carried out in a hot press, a few of the details of the gluing operation just described will, of course, be changed to fit the adhesive. With hot-pressing adhesives, the assembly period can ordinarily be considerably longer, and the gluing operation will involve a loss rather than a gain in moisture. The time in the press will be greatly shortened, but a conditioning period should follow the gluing, just as in the case of cold-setting glues. The same precautions involved in securing an accurate fit of the surfaces and preventing endwise slippage are recommended as in cold pressing. The use of dry glues reduces somewhat the danger of end slippage. Some operators have found it practical to use electric strip heaters between scarf joints in a cold press, either to accelerate the setting of the cold-setting glues or to provide a means of curing hot-setting glues where lamination thicknesses permit.

5.411. Scarf Joints in Plywood. After the scarf joints in plywood have been machined, they should be glued as described in sections 5.271 and 5.40. Figure 5–36 shows a special narrow, multiple-opening hot press for gluing scarf joints in plywood. The extensions are for supporting the plywood and also may be used as clamp supports to prevent end slippage. In hot-press gluing of scarf joints with liquid glues of low viscosity, two applications of glue to both of the contact surfaces are often made. Several minutes are allowed to elapse between the two applications of glue.

Other than the points mentioned, the gluing of scarf joints in plywood follows the same basic procedure as does gluing of scarf joints in solid stock.

5.412. Serrated, Finger, and Stepped Scarf Joints. Various designs of joints, such as serrated, finger, and stepped, may also be considered as examples of scarf joints. As a general rule, they are difficult to machine accurately and to glue with

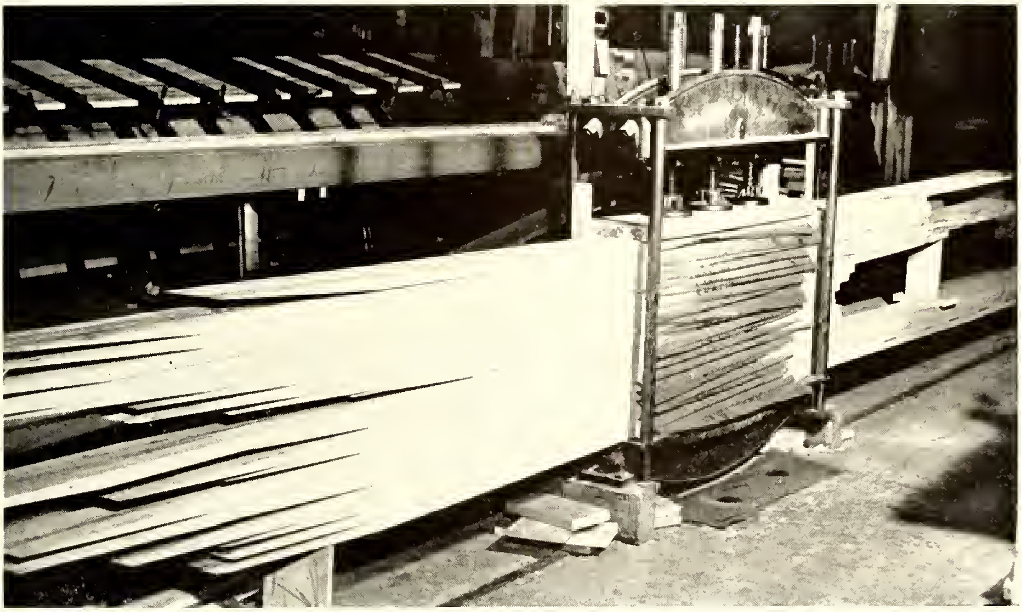

FIGURE 5-35.—Screw press used in gluing scarf joints. In presses of this type some provision should be made to prevent end slippage (sec. 5.4100).

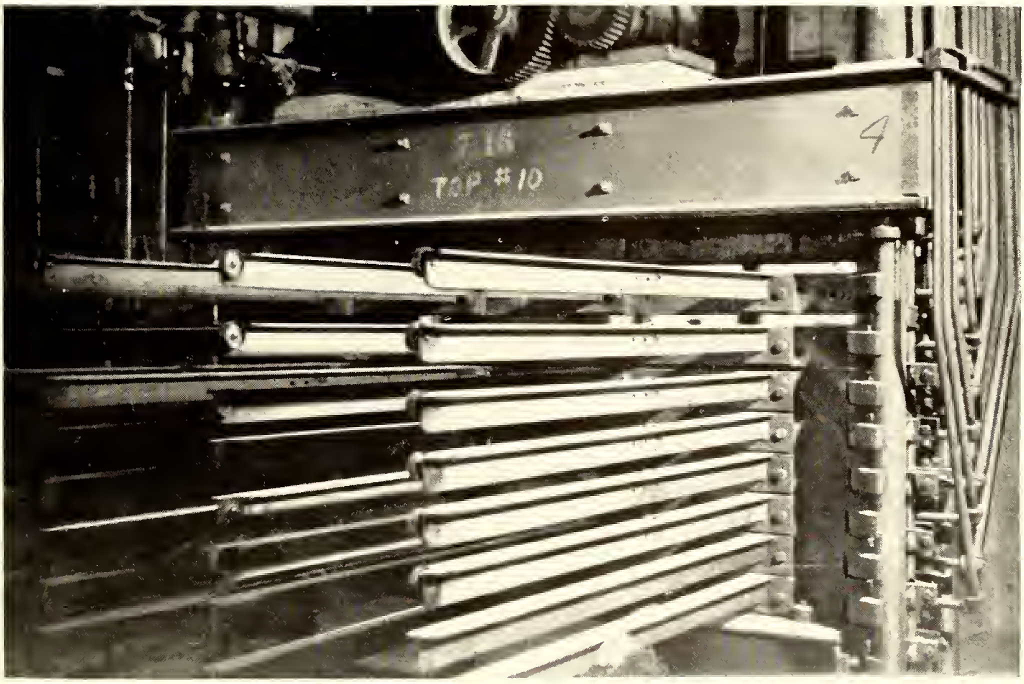

FIGURE 5-36.—Special narrow, multiple-opening hot press used for gluing scarf joints in plywood.

assurance of producing joints of high and uniform quality. Consequently, they find little use in aircraft construction, and are not recommended.

5.42. Gluing Straight Laminated Members. The laminating of flat, straight members, such as spars and spar flanges, is a simple gluing operation complicated only by the large size of some of the members produced. The species involved are chiefly spruce and other light-weight wood. The large pieces, of course, require the use of gluing presses of corresponding size and often machine glue spreaders to speed the operation and stay within permissible time limits for the assembly period.

5.420. Glues. The thickness and size of most laminated members preclude the use of hot-setting glues except where heated rooms with controlled humidity or electrostatic heating equipment are available (sec. 5.264). Consequently, the choice of glues is generally limited to those of the cold-setting types. The glues used should conform to the current issue of the Army and Navy specification covering the type of glue selected.

FIGURE 5-37.—A type of screw press used in gluing flat laminated stock.

5.421. Presses and Clamps. The most common method of applying gluing pressures in gluing laminated members is by means of screw presses as illustrated in figure 5-37. The major problem in using this type of equipment is to insure an adequate but not excessive pressure. The load applied by a screw may be mesaured by the use of a compressometer, by means of a torque wrench (fig. 5–16), or may be approximated by calculation (sec. 5.251).

Occasionally, presses are used that are similar in basic design to the screw press illustrated, but with the pressure applied by means of hydraulic jacks equipped with pressure-indicating dials. With equipment of this design, the pressures can be measured and controlled more conveniently than with a screw press. The travel of the head of the jack, however, is ordinarily more limited than the travel of a screw, and more time will be spent in blocking if members of different thicknesses are to be glued in the same press. Further, the number of hydraulic jacks in a press will usually be small compared with the number of screws in a press of the same size. Consequently, the caul boards must be considerably heavier to insure adequate distribution of pressure.

Laminated members whose depths vary throughout their length can be produced by the use of shorter laminations at the thicker sections. On construction of this type, the continuous laminations should always be on the side most highly stressed in tension. Gluing of such assemblies is accomplished with "stepped" cauls. Each step in the caul should be accurately coordinated with the thickness of the corresponding lamination. As a further precaution, it is advisable to line the stepped caul with a uniform thickness of felt or rubber securely glued in place. Waxed paper or cellophane should be used against this surface to prevent its being covered with glue. In the application of pressure to laminated members it is advisable to work from the center towards the ends or from one end. This procedure allows the laminations to slip into place.

Where enough laminated members of one thickness are required to justify a special press, one can be constructed that makes use of hydraulic or air pressure distributed over the entire platen area. In a press of this type, a diaphragm is placed below the bottom platen. The diaphragm may consist of fire hose closed at one end and attached to air pressure equipment at the other. The stock to be glued is laid between the platens and the gluing pressure is applied by air pressure on the diaphragm or hose. In a press of this design, the travel of the head is limited and it is suitable for the gluing of stock of only one thickness. Some commercial hot presses make use of the same principle and attain greater flexibility by providing for movement of the head of the press. In such a press, the platens are closed mechanically and only the gluing pressure, accomplished with relatively small movement, is exerted by the diaphragm.

5.422. Final Conditioning. If the laminations are three-eighths inch or thicker, the stock, after removal from the press, should be conditioned for 3 to 7 days at ordinary room conditions, or for 1 to 3 days at 100° to 120° F. (with humidity control) before final surfacing operations. The joints will be strong enough to permit initial machine work in 2 days at ordinary conditions. If the laminations are one-eighth inch or thinner and glued with casein glue, the conditioning period should be extended to 1 to 3 weeks when stored in ordinary room conditions or 4 to 12 days in a kiln at a temperature of about 120° F., depending on the size of the member. For conditioning other constructions see section 5.28.

5.43. Gluing Curved Laminated Members. In the preparation of curved, laminated parts, the bending and gluing are usually done in one operation. After the glue is set, the laminated construction will retain essentially the curvature of the form. Examples of laminated parts frequently found in aircraft work are spar flanges, bow ends for wing tips, bulkhead rings, gas-tank supports, and wing rib caps in highly stressed sections.

In gluing curved, laminated parts, the fundamentals of the operation are the same as in gluing flat laminations.

5.430. Methods of Applying Pressure. The application of gluing pressure to curved members is usually more complicated than in the case of flat laminations. If the curvature is only moderate, possibly the easiest way to apply gluing pressure is by means of simple male and female forms prepared from wood blocks (fig. 5–38, *A*). When loaded, such forms can be laid in screw or hydraulic presses and pressure applied just as in gluing flat stock. If many small curved items of the same design are to be made, it may be convenient to prepare a series of forms and use them in a hydraulic press as illustrated in figure 5–39.

Another laminating press, employing electric strip heaters to accelerate the setting of the glue, is illustrated in figure 5–38, *C*. The force is applied to the movable form by screws, C-clamps, or hydraulic pistons. A piece of thin, high-carbon steel 0.005 to 0.010 inch thick is attached to the inside surfaces of both forms. It is advisable to use a sheet of felt or rubber on one form to compensate for inaccuracies in the fit of parts. To facilitate uniform heating, the strip heater must be uniform in cross section. The electrical energy necessary to produce the desired temperature in the strip heater will depend on several variables, such as size, shape, and construction of forms, but a power consumption of about 1½ watts per square inch of heater strip has been found to be generally applicable. A voltage of less than 30 is advisable for the safety of the operators. Power is usually supplied by a step-down transformer in series with a variable voltage transformer or by a welding machine. In use, the jig is loaded and pressure applied before the power is turned on.

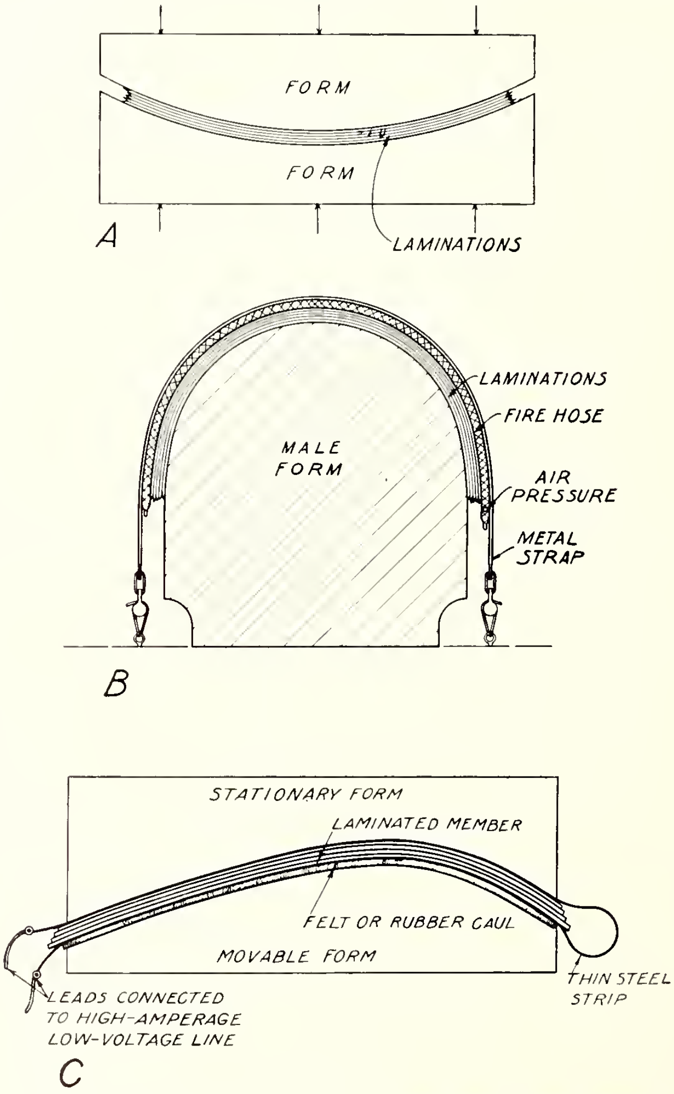

FIGURE 5-38.—Diagrams of apparatus used in gluing curved laminated members.

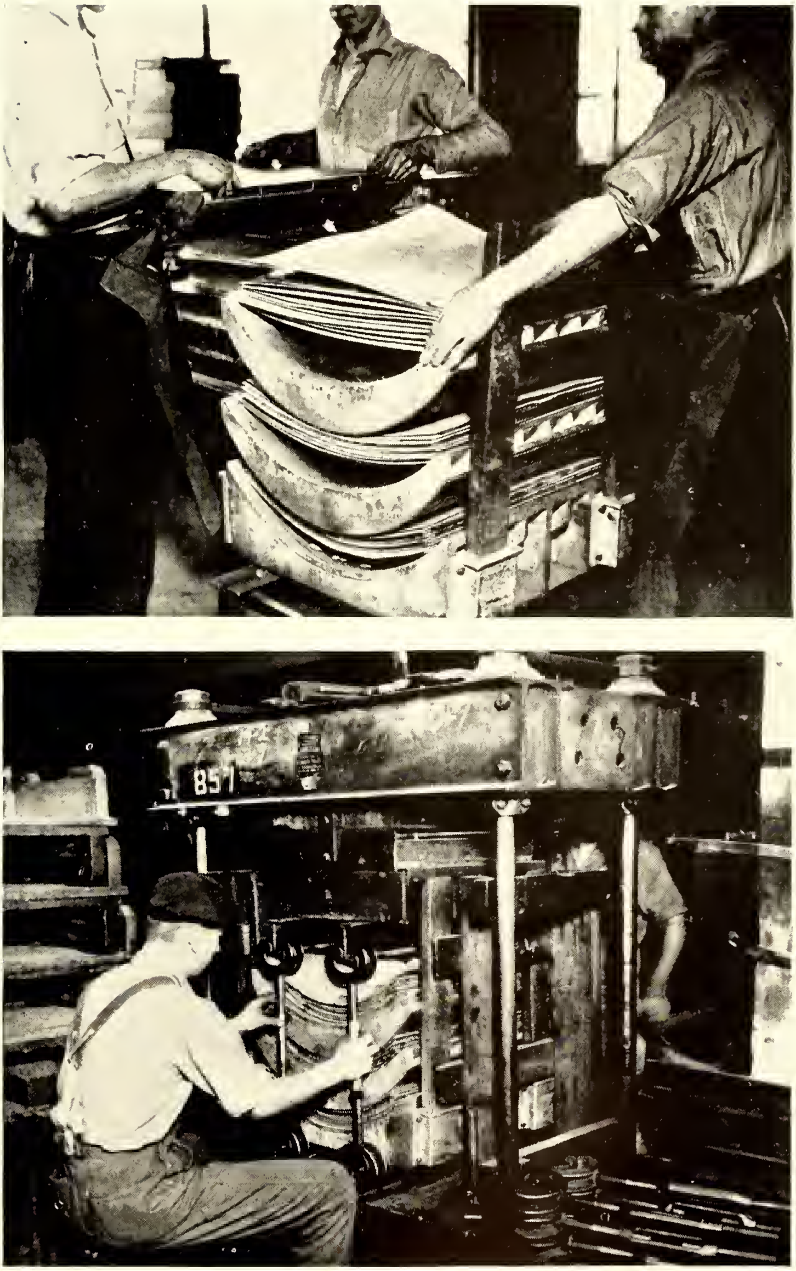

Figure 5-39.—Forming curved plywood parts in quantities by cold-pressing technique.

In gluing curved, laminated members whose depth varies throughout the length, the use of step cauls permits the use of shorter laminations at the thicker sections. The same precautions apply to both curved and straight members of this type (sec. 5.421). A horizontal laminating press which can easily be adapted to curved, stepped cauls is illustrated in figure 5-40.

As the curvature of the members becomes greater, it will be found more and more difficult to secure uniform distribution of pressure by the use of only the simple male and female forms. If the curve is circular or nearly so, it is possible to use tension bands of metal around a male form, in which case the radially acting pressure in pounds per lineal inch of length in direction of the axis of curvature is equal to the tension per inch of width on the strap (in pounds) divided by the radius of the circle (in inches). If one part of the member is curved and the other nearly straight, it will be difficult to use tension bands alone, because the pressures will then be very low on the straight portion. One method of overcoming this difficulty is shown in figure 5-38, *B*, in which a fire hose has been laid between the tension band and the work. The fire hose is closed at one end and connected to air pressure at the other. In its use, the laminations are spread and laid in place and the tension band tightened. Air is then admitted into the hose. If the shape deviates much from circular, or if there are straight portions, it may be necessary to interpose filler blocks between the hose and the tension band because, with fluid pressure in the hose, the band tends to assume a circular shape. It is apparent that the setting of resin glues could be accelerated if warm water instead of air were used in the hose. The male form can also be made in such a way that hand clamps may be attached around the circumference. With a jig of this description, the work is laid on the form with a caul of wood or metal over the last lamination and clamped to the form by means of the hand clamps. While such a jig or form is simple to make, more time to clamp up the work will be required than with the air-pressure type and probably the pressure will not be so evenly distributed.

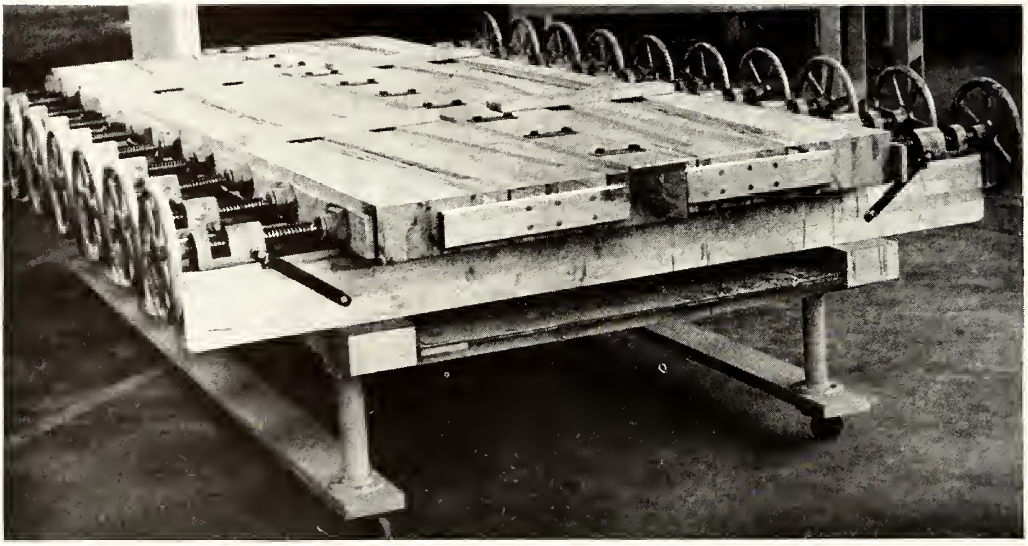

FIGURE 5-40.—Horizontal laminating press.

If the laminated member is a complete ring, as, for example, a complete bulkhead ring, the manufacturing difficulties are considerably increased. One method consists in using a continuous lamination wound spirally around a form with the gluing pressure applied by tension of the lamination alone or aided by belt pressure. This method is illustrated in figure 5–41 on a closed member of circular shape. Application of this method requires that the veneer first be spliced end to end by means of scarf joints until a sufficient length is provided to form the complete ring. It would be possible to manufacture much the same product by laminating the rings in half sections and later joining pairs of half sections with scarf joints.

5.431. Radius of Curvature. Precise data on the minimum curvatures to which veneers of different thicknesses and species can be bent are not available, but the information contained under section 5.68 is suggested as a guide.

5.432. Time Under Pressure. Conservative practice suggests that the time under pressure should be extended somewhat beyond the minimum suggested for flat gluing.

5.433. Final Conditioning. Curved, laminated members should be given a final conditioning treatment similar to that recommended for straight laminated members (sec. 5.422).

5.44. Assembly and Gluing of Ribs. The size and number of ribs to be made will have considerable bearing on the choice of the procedure in construction. A few ribs of one size and shape can probably be produced most easily and economically by nail gluing, although in such cases many are glued in simple jigs with the gluing pressures applied by hand clamps. For mass production of ribs, the more elaborate jigs will probably prove most useful. Ribs of the control surfaces, ailerons, stabilizers, elevators, and rudders are usually smaller and their construction often simpler in design than that for wings (sec. 5.46). In place of braces, a single sheet of plywood, with or without lightening holes, may be used as web, and cap strips glued to one or both sides to form a channel or an I-section. On the other extreme, ribs in the center section, particularly in larger aircraft, may have cap strips whose cross section is such that laminated construction must be used to provide the proper size and bending properties. The general methods described here, however, should prove suitable, and the general principles applying to the use of the glues and conditioning practice after gluing will apply.

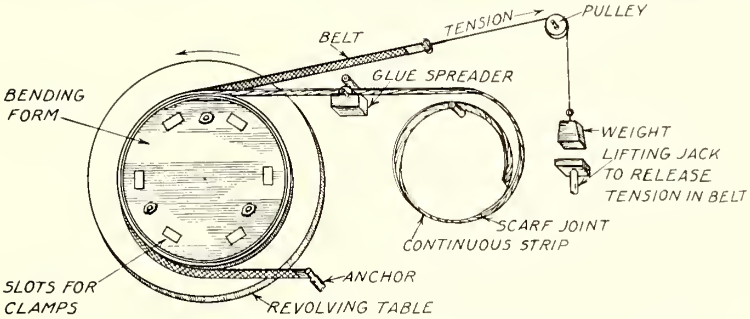

FIGURE 5–41.—Method of gluing a laminated member in the form of a complete ring.

5.440. Cold-press Gluing.

5.4400. Nail Gluing. The most commonly used method of wing-rib construction provides that the cap strips and braces be laid in a jig so designed that the strips and braces are held by blocking in their proper positions (fig. 5–42). Small plywood gusset plates, often triangular in plan and about 2 inches in their longest dimension, are then spread with glue and nailed in place. The nail spacing and nail size vary according to the size of the cap strips and braces. When the cap strips are approximately ⅜ by ⅜ inch and the gusset plates are 3/32-inch plywood, ⅜-inch No. 20 nails

FIGURE 5-42.—Constructing wing ribs by nail gluing.

spaced about ¾ inch apart are suggested. The surfaces of the cap strips and braces should be true and smooth, and the nails should be driven home snugly.

An adequate amount of glue should be spread over the joint area (sec. 5.404), but the natural tendency is to use more than is necessary, so that the main precaution required is to see that all parts of the joint are covered. Single spreading on the gusset plate is adequate and most convenient. Because of the nature of the operation, the assembly period is short and requires no special regulation other than training the operator to spread only a few plates before nailing. The common practice is to spread one gusset plate, nail it in place, then spread a second, nail it in place, and so on; but, where desirable, a few plates can be spread and laid in place in advance so long as the interval between spreading and nailing on any one plate does not exceed 10 minutes. When the gusset plates have been nailed and glued to one side, the rib is removed from the jig and the gusset plates are nailed and glued to the other side.

5.4401. Manual Pressure Gluing. A second method, that of manual pressing, has in some cases been adapted to the cold gluing of wing ribs, but the method is not recommended for general use because of the difficulties of insuring proper magnitude and distribution of gluing pressure and of maintaining proper limits on the assembly period. In this type of operation, a jig is prepared for each size of rib. The jig consists essentially of two metal plates about three-eighths inch thick, to one of which short metal rods are attached—usually by threading the ends of the

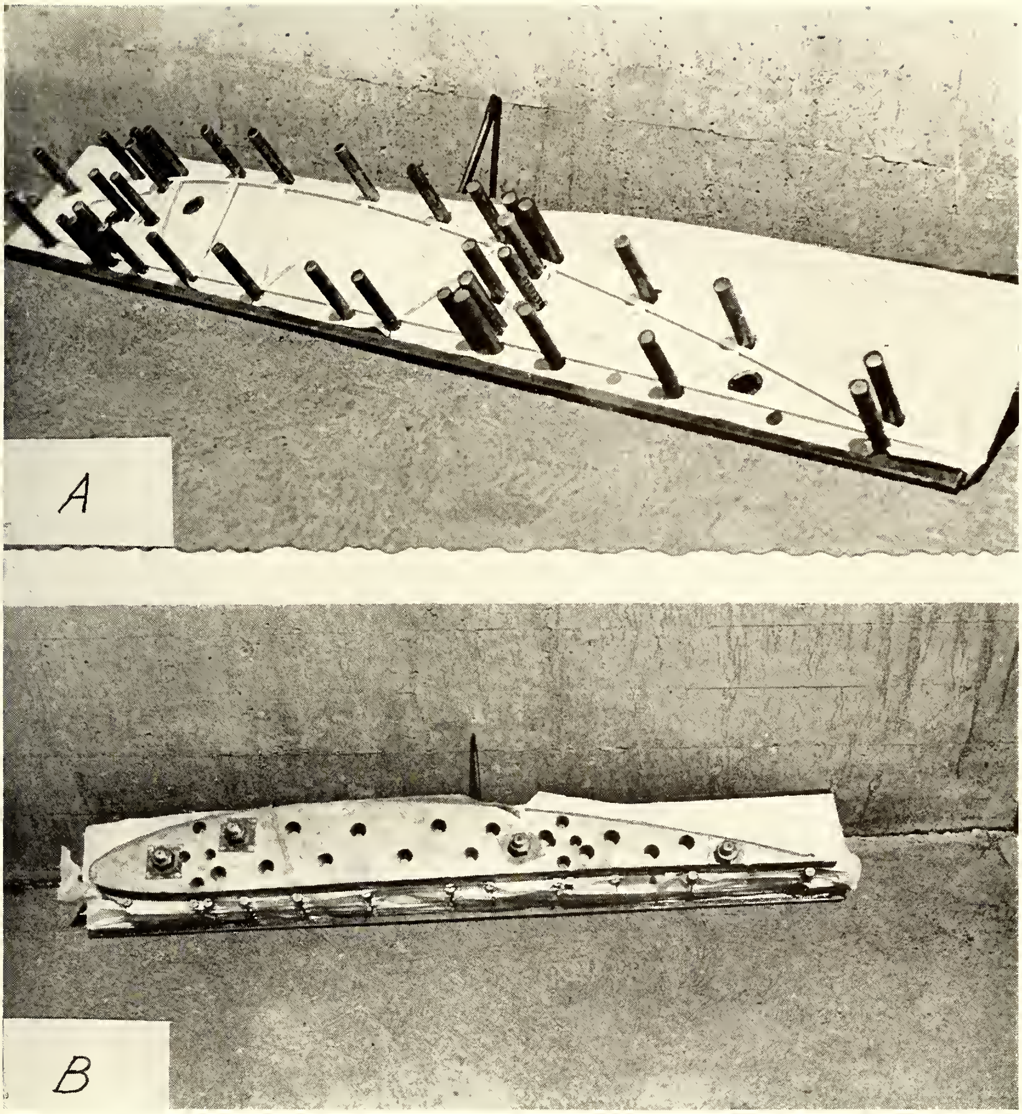

FIGURE 5-43.—Jig for assembling and pressing several wing ribs in one operation.

rods and tapping the plates—in such positions that they hold the cap strips, braces, and gusset plates in their proper position (fig. 5-43). Holes are bored in corresponding positions in the upper plate. Additional pressure rods, threaded at the top and attached to the bottom plate, extend through the top plate when the jig is loaded, nuts are screwed on the threaded rods, and the gluing pressure is applied by tightening the nuts. With this method, some care is required in locating the strain rods to avoid unequal pressure distribution and localized crushing. It is advisable to use a torque-indicating wrench to avoid excessive pressure. The gluing pressure can also be applied, of course, by external screws, clamps, or presses.

In operation, one set of gussets, cap strips, and braces after another is spread with glue and laid in place until the jig is full. The top plate is then laid on and the gluing pressure applied. It is advisable to lay a caul of thin plywood upon each rib to promote uniform distribution of pressure and a sheet of waxed paper on each side of each rib to prevent excess glue from causing the ribs to stick together or to the cauls.

The principal disadvantage of this system is the danger of exceeding the allowable assembly period. The assembly periods should not exceed 20 minutes and the gluing pressures should be between 100 and 200 pounds per square inch, depending on the species used. Some difficulties are likely to be encountered when this system of rib gluing is first tried. For larger ribs, the forms are heavy and mechanical lifting hoists may be desirable. Loading the jig is not a rapid process; hence, the number of ribs that can be laid up at one time in one jig will be limited by the permissible assembly period of 20 minutes from the time spreading starts on the first rib until gluing pressure is applied. If the gusset plates are continuous strips, 10 to 15 ribs of medium size can be laid within the time limit, but, if the gussets are in the form of small patches, the number of ribs per jig will be considerably reduced.

After the ribs are removed from the press, they should be conditioned before final machining for 2 to 3 days at room temperatures, or 1 day at 120° F. with humidity control.

5.441. Hot-press Gluing. Gussets are often glued to cap strips in a rapid-closing hot press. To carry out this operation, a jig is made of comparatively thin metal (approximately one-sixteenth inch) equipped with thin metal angles welded to one surface to hold the ribs, braces, and gussets in their proper positions. The height of these angles must be somewhat less than the sum of the thicknesses of the cap strips and the gusset plates, so that the gluing pressure will be exerted on the joint and not on the guide blocks.

5.4410. Gluing. In the gluing operation, the gusset plates for one side of the rib are coated with glue and laid in place, the cap strips and braces are inserted in their proper places, and the top gusset plates are spread with glue, laid in place, and—since they may extend well above the guide blocks—fastened lightly with a few nails. The assembly is then placed in a hot press, where the gluing operation is completed under heat and pressure.

5.4411. Glues. Synthetic-resin glues are best suited for this type of operation, the choice between the different types depending somewhat on the hot-press equipment available. Hot-press urea, fortified urea, phenol, and melamine-formaldehyde glues can be used in single or multi-opening hot presses of conventional design (figs. 5–14 and 5–44). The low-temperature, phenol-formaldehyde glues, which do not cure at ordinary room temperatures, and the cold-setting urea resins are also adapted for use in hot presses. There is great danger of precuring when low-temperature and cold-setting resin glues are used in hot presses. If the press is slow in closing, either because of delay by the operator or because of a slow-closing mechanism, the glue may set before the pressure is applied, and faulty joints will result. Quick-closing, single-opening hot presses (fig. 5–44) are best adapted for use with low-temperature and cold-setting resin glues. Although casein glues can be used in hot presses, they do not set as rapidly and are not as well adapted for hot-pressing operations as are the resin glues.

With the hot-setting resin glues, the temperature of the platens may well be that used in the conventional gluing of hot-pressed plywood (sec. 5.263). The rate of setting of the low-temperature phenol and cold-setting, urea-resin glues is discussed in section 5.263. With the cold-setting, urea-resin glues in particular, the recommendations of the glue manufacturer on maximum permissible temperature should be observed and tests made to confirm the quality of the resulting bond. In all hot-press gluing, the metal jigs must be cooled between operations or the glue on the lower gusset plate may cure while the rib is being assembled.

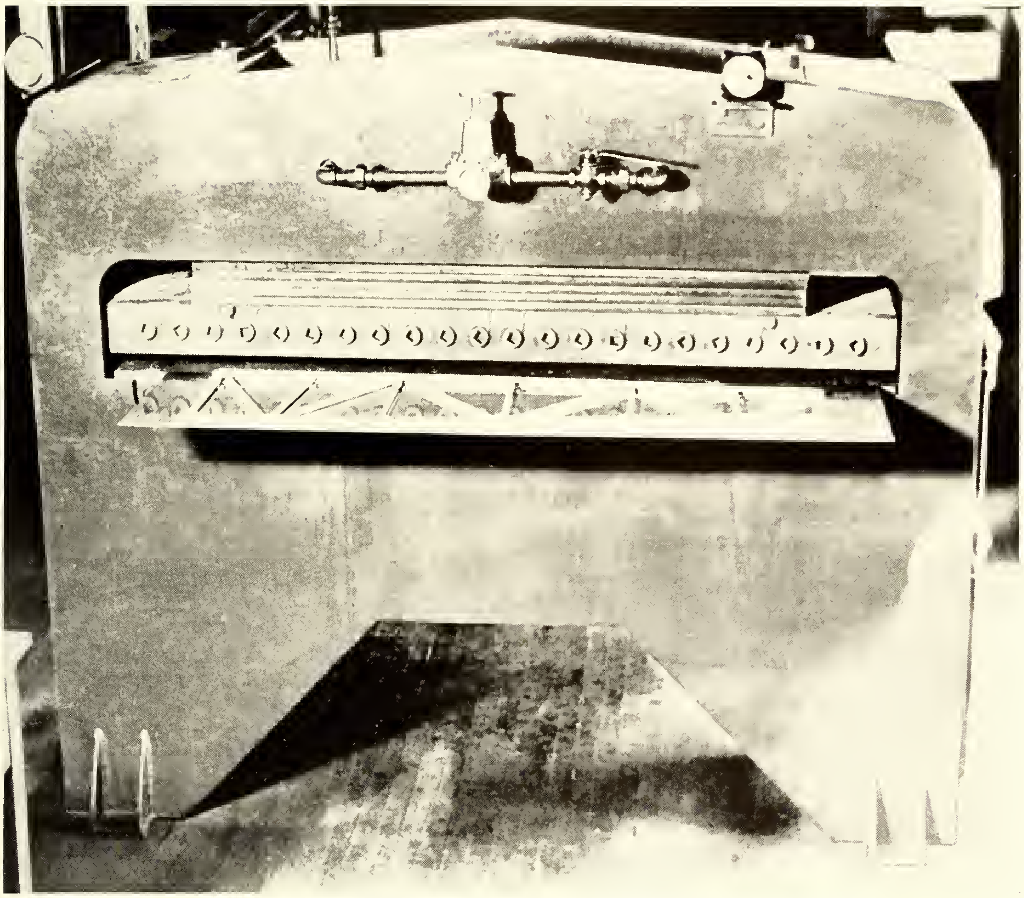

Figure 5-44.—Quick-closing, fire-hose hot press for assembling ribs and similar small parts.

5.4412. Pressure. The gluing pressure should be calculated on the basis of the area of the glue joint and should conform to previous recommendations for the glues used.

5.4413. Final Conditioning. During the gluing operation, moisture will be lost, and the ribs should therefore be allowed to condition before the final machining operation. In contrast to cold pressing, the conditioning involves a regain rather than a loss of moisture. This increase in moisture content can best be accomplished in a kiln at elevated temperatures and humidity adjusted to an equilibrium moisture content of about 10 percent. Conditioning in an ordinary shop without adequate humidity control during the winter will be slow and unsatisfactory.

5.45. Assembly of Box Spars. The assembly gluing of box spars consists of gluing the filler or reinforcing blocks between the flanges and gluing plywood webs to the sides. In most cases, the grain of the reinforcing block is perpendicular to that of the spar flange. In other cases, it is at an angle of as much as 60°. If the filler blocks are of plywood, the grain of approximately half the plies will run at right angles to that of the spar flanges and, on this portion of the surface, end grain will be glued to side grain. If the grain of the filler blocks is perpendicular to the flange, or nearly so, the recommendations for the gluing of scarf-joint surfaces should be followed. In particular, the glue mixture should be thickened and the maximum pressures permitted by the species should be used (secs. 5.271 and 5.4101).

5.450. Glues. The choice of glues for gluing both the filler blocks and the web is usually limited to those of the cold-setting type. In some cases it may be possible to glue the web to the flanges in a hot press, and in such cases a hot-setting resin can be used. The use of hot-press glues, however, will be limited to those cases where the web is thin.

5.451. Pressure. In calculating the gluing pressure, the area of contact between the filler blocks and the spar flanges or between the web and the filler blocks and flanges should be considered rather than the total surface area. The width of the filler blocks should equal that of the flanges. In gluing, the blocks should be carefully aligned with the surfaces of the spar flanges to minimize the surfacing necessary before gluing on the webs. The time under pressure should not be less than 4 hours at ordinary room temperatures, and the assembly should be allowed to condition 3 to 5 days at room temperatures before preparing the surface for gluing to the web.

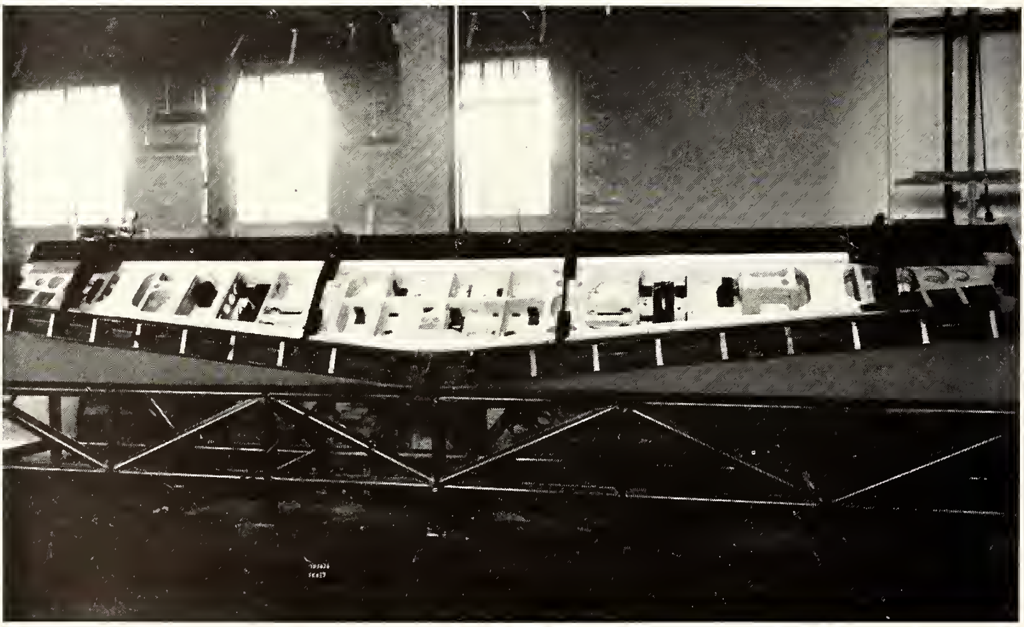

FIGURE 5–45.—Jig for positioning and gluing filler blocks to spar flanges in a spar of complex design.

5.452. Filler Blocks. In gluing the filler blocks of a box spar, the method of applying the pressure will vary with the design of the spar. Filler blocks of simple design in small spars may be glued in place with hand clamps, provided that a sufficient number of clamps is used to obtain adequate pressure (sec. 5.251 and table 5–13). Filler blocks can be glued in larger spars by the use of cauls and screw presses (fig. 5–37).

If the job involves large numbers of complex spars, special jigs are desirable to assist in proper alignment of the filler blocks and in convenient application of the gluing pressure. One such type of special jig is illustrated in figure 5–45. The location of each filler block is indicated by a diagram or by mechanical stops on the plate upon which the flanges and blocks are placed. One spar cap rests against a rigid metal caul plate; the opposite cap is laid against a movable caul plate that may be of wood or metal. In this design, a fire hose is laid between the movable caul plate and a rigid supporting member. When the filler blocks have been surfaced to fit and spread with glue they are laid in place and the gluing pressure applied by admitting air into the hose. The pressure could also be applied by screws through the fixed support bearing against the movable caul board, or by levers that actuate eccentrics. Applying air pressure through hose, however, has the advantage that the pressure is uniform and is easily measured.

5.453. Gluing Webs. Gluing of the webs to the flanges and filler blocks can ordinarily be done most conveniently in a conventional screw-type press (fig. 5–35). As mentioned previously, this gluing might be done in a hot press in special cases. Specially designed steam or electrically heated fire-hose presses are sometimes used for this purpose. A large steam heated press of this type is illustrated in figure 5–46.

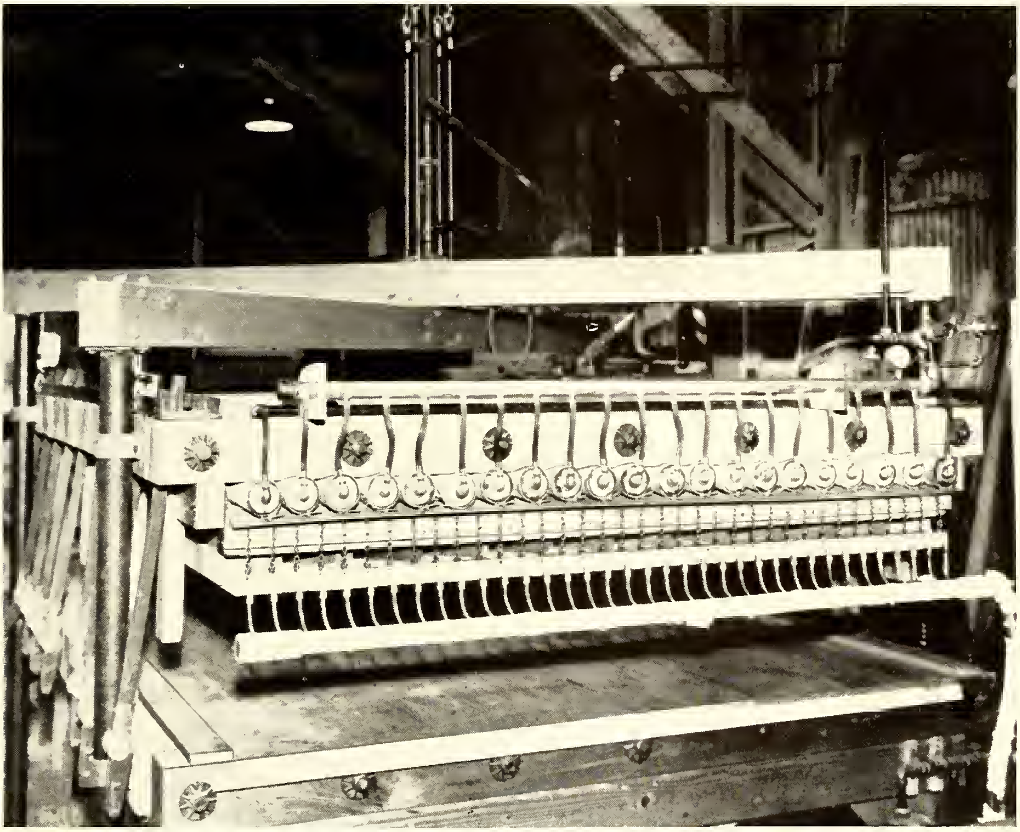

FIGURE 5–46.—Specially designed, steam-heated hot press used to glue plywood to framing.

5.454. Final Conditioning. After removal from the press, the completed spar should be allowed to condition at least 2 days before initial machining and from 3 to 5 days at room temperatures before final surfacing.

5.455. Interior Finish. Gluing the interior surfaces of the flanges and filler blocks involves masking or otherwise protecting the glue-line area previous to the finishing, as described in section 5.7.

5.46. Assembly of Wing and Fuselage Frames.

5.460. Fabric-covered Wing Frames. The ribs for fabric-covered wing frames are often made in one unit that includes the leading edge, center section, and trailing edge. The cap strips are continuous and extend across the top and bottom of the

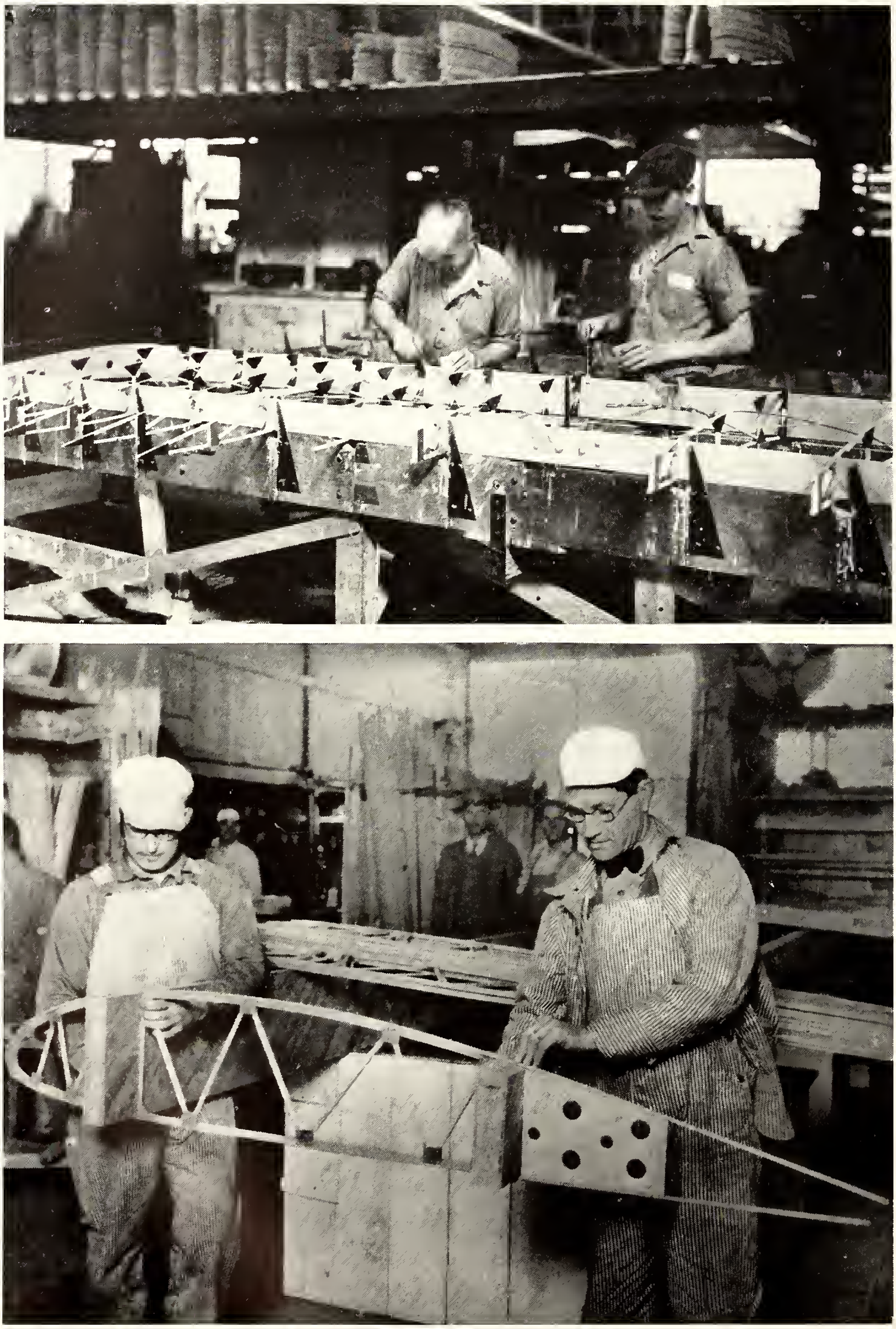

Figure 5-47.—Assembling wing ribs and spars.

spar. Attaching ribs of such design to the spars offers no particular difficulty and requires no elaborate jig. Ordinarily, the ribs are slipped over the ends of the spar, properly held by simple positioning jigs, and glued in place (fig. 5–47). The gluing pressure is ordinarily applied by small nails.

5.4600. Reinforcing Blocks. The joint between the rib and the spar is sometimes reinforced by corner blocks or by small plywood angles, as in figure 5–48. Solid reinforcing members are usually glued in place by nail gluing, although the pressure could be applied with hand clamps. Plywood angles can be glued in place by special clamping devices. A suitable clamp for gluing four angles in place in one operation is illustrated in figure 5–48, *C*.

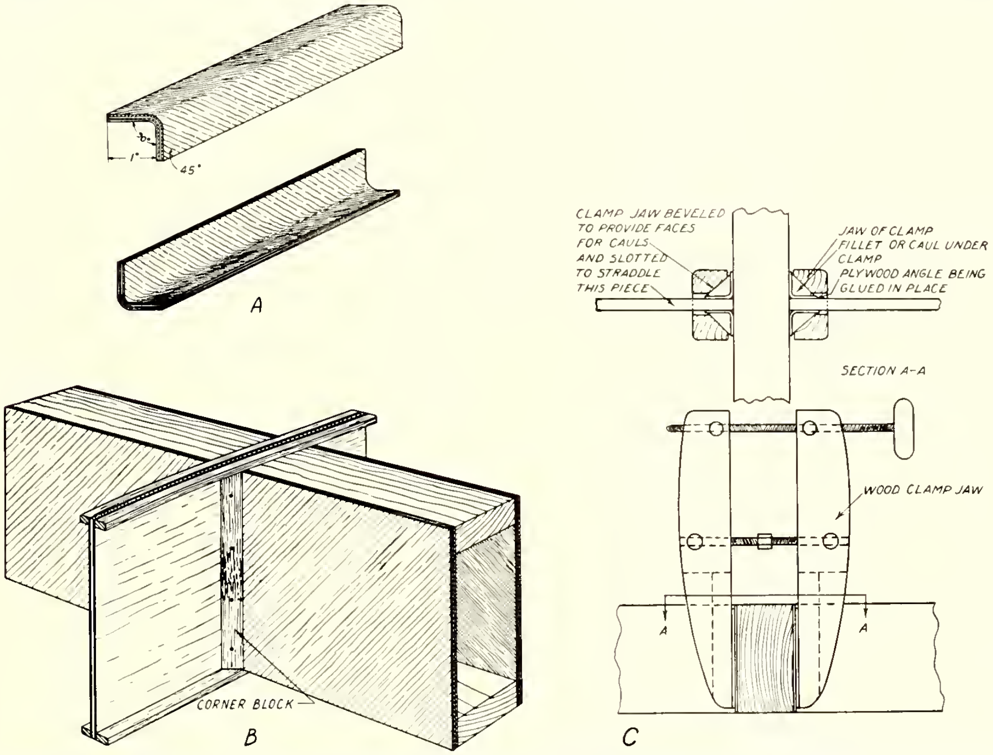

FIGURE 5–48.—Reinforcements for the joints between the wing ribs and spars: *A*, plywood angles; *B*, triangular, solid-wood blocks; *C*, hand clamp for gluing plywood angles in place.

5.4601. Machining. For a wing that is to be covered with fabric only, the amount of machining to true the surfaces after the ribs are in place will be limited. If the wing is covered with fabric over a partial covering of plywood (fig. 5–49), more surfacing will be required to form a smooth junction between the ribs and plywood-covered areas.

5. 461. Plywood-covered Wing Frames. Ribs in wings that are covered with plywood are often in three sections, the leading-edge section, the trailing-edge section, and the section between the front and rear spar. In this case, more elaborate jigs are required to locate the ribs in the proper position and to hold them at the correct angle while they are being glued in place. Frequently the ribs for the leading edge are fastened in position first (fig. 5–50), usually by nail gluing them to the spar. The plywood cover is frequently attached to the leading edge in the same jig as soon as the leading-edge ribs have been glued in place and surfaced (usually by floating (sec. 5.658)) to insure a good contact surface. The spar, complete with leading edge, is then transferred to another jig where the center-section ribs are attached between front and rear spar. For the most part, these ribs, like the leading-edge ribs, are nail glued in place. The joints are sometimes reinforced with blocking or with plywood angles, and sometimes with a strip of plywood glued to the surface of the spar flange and extending over a portion of the ribs (fig. 5–51).

Ribs in the center section of a three-piece wing are frequently heavy and designed to carry high stresses. These ribs likewise are often fastened in place by nail gluing, with or without reinforcing blocks or angles, but occasionally they are bolted to the spars. The jigs for holding the structure in place while the ribs and other parts of the structure are attached are often large and complex.

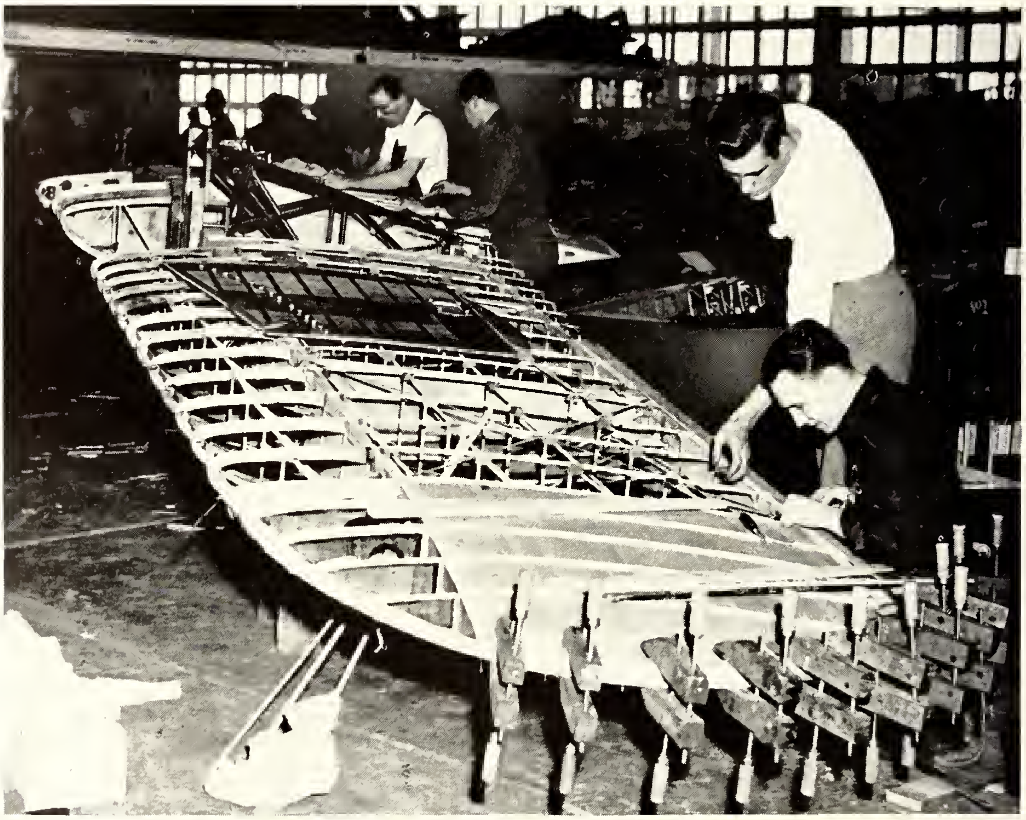

FIGURE 5–49.—Assembling a wing that is to be covered with fabric over a partial covering of plywood.

On the other extreme, the ribs for the trailing-edge section and of the control surfaces are usually small and light and require only simple jigs to insure their proper positioning. Nail gluing is used almost exclusively in fastening the ribs in position in these small assemblies.

5.4610. Glues. The choice of glues for use in assembling the wing frames is limited to those of the cold-setting types except in those cases where it is possible to accomplish setting by the application of heat.

5.4611. Glue Spread. The amount of glue spread should conform to recommendations (sec. 5.403). The natural tendency of the workmen will be to spread more than is necessary on the small surfaces involved, so the only precaution necessary is to see that all parts of the contact surfaces are covered.

5.4612. Pressure. Where clamps can be used, pressures of approximately 150 pounds per square inch are advisable. If the joints are nail glued, the size of the nails and nail spacing will vary with the size of the members. One row of nails for each one-half inch in width is suggested, with a nail spacing of approximately 1 inch in each row and the nails in each row staggered with respect to those in adjacent rows. The length of the nails should be such as to reach at least three-eighths inch into the wood beneath the joint.

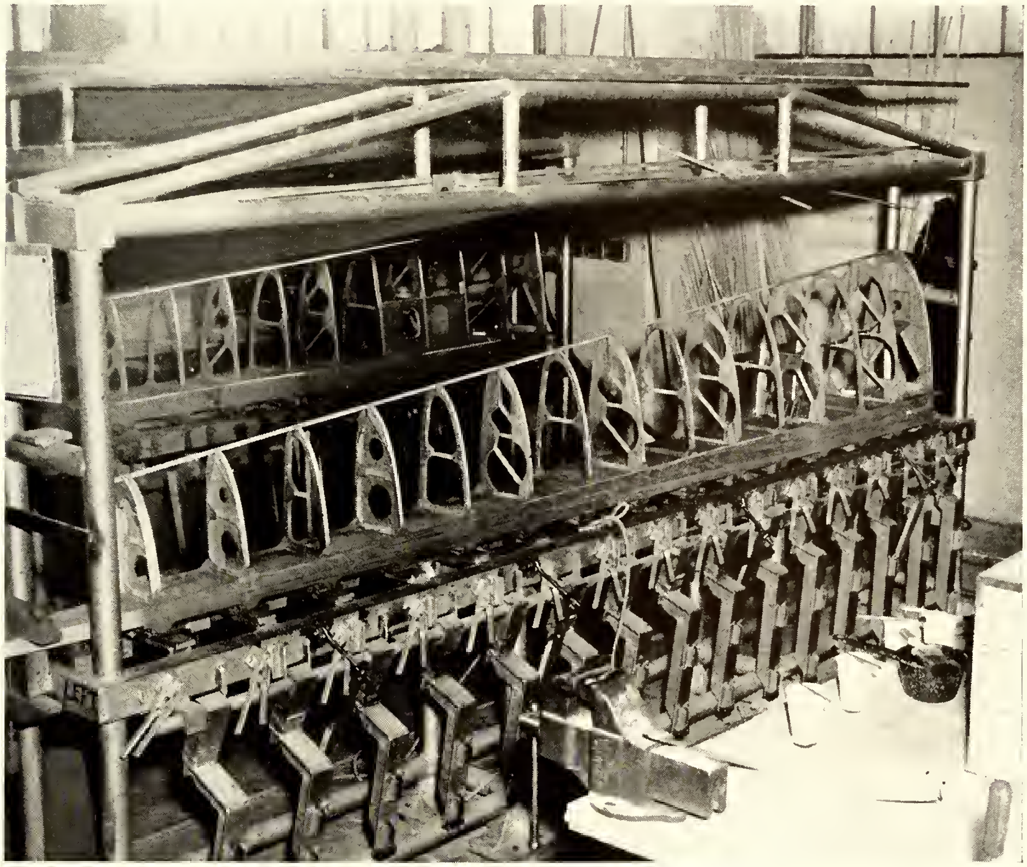

FIGURE 5-50.—Jigs for locating leading-edge ribs in proper positions.

5.4613. Pressure Period. If clamps are used, the joints should remain under pressure for at least 4 hours at 75° F. It is assumed that, if nails are used, they will be left in place and that the assembly will be so handled that the joints will not be disturbed before the glue has set. Banks of infrared lamps or kilns are sometimes used to accelerate the cure of joints in frame assembly. When either method is used, certain precautions should be observed. The temperature should not be sufficient to damage either the glue or the wood and the relative humidity should be regulated to minimize drying and consequent changes in dimension during the curing period. Tests should be made to substantiate the quality of the joints produced.

5.4614. Final Conditioning. The conditioning period following gluing of about 2 days at ordinary conditions is sufficient to permit the joints to reach approximately maximum strength. A longer conditioning period to permit complete diffusion of moisture away from the glue joint is not necessary.

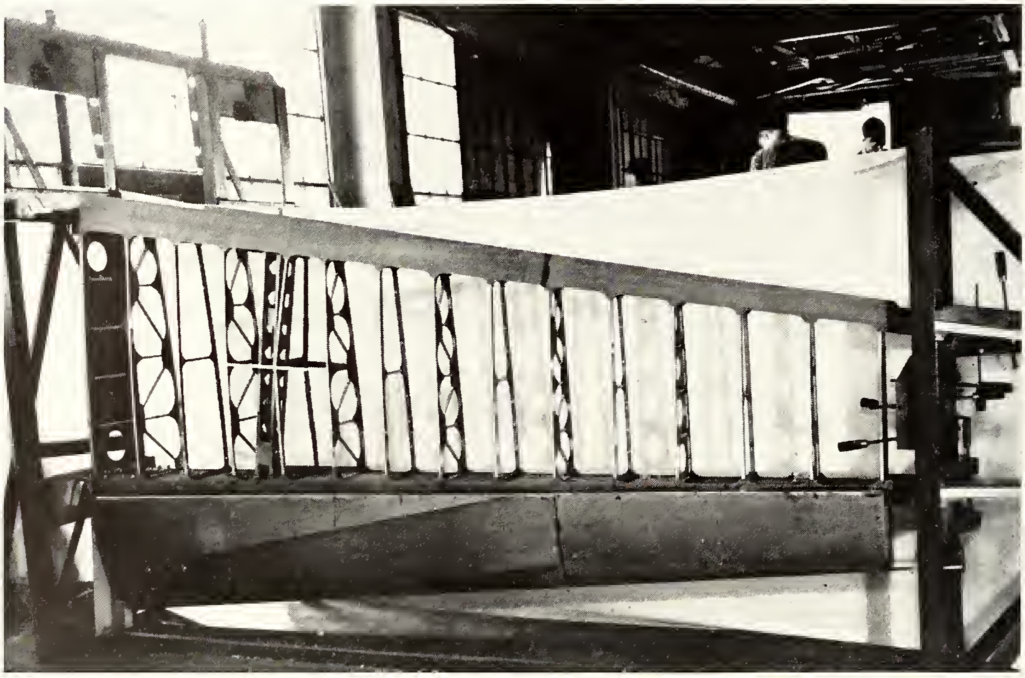

FIGURE 5-51.—Ribs in place between front and rear spars of wing section.

5.462. Assembly of the Fuselage Frame. Assembling the fuselage frame consists essentially in holding the bulkhead or fuselage rings in proper position while the longerons are being fastened in place. The rings may be laminated stock (sec. 5.68); flat plywood formed from panels of sufficient thickness; or combinations of solid wood, plywood, and laminated stock. Larger fuselage rings may be of box-section construction.

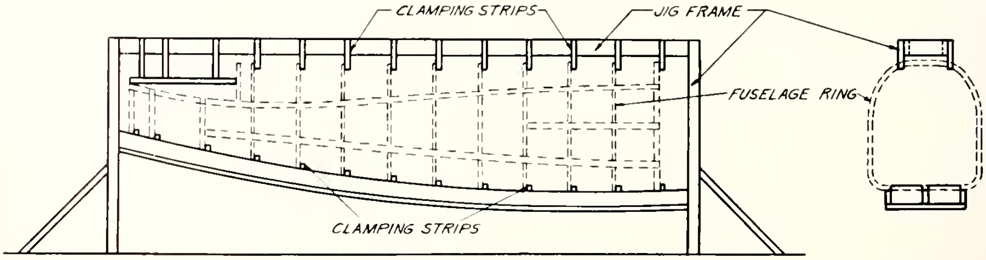

FIGURE 5-52.—External type jig for assembling fuselage frames.

5.4620. Jigs. The jigs used for supporting the fuselage rings are usually of two types, external and internal. The external type is essentially a frame enclosing the fuselage with stops or blocks at the proper positions to which the fuselage rings are clamped (fig. 5-52). With an external jig of this type only a part of the fuselage covering can be attached at one time, so that a second jig is necessary when the fuselage advances to the final covering operation. With the internal type of jig for assembling the fuselage rings, a rigid and comparatively large member extends longitudinally through the fuselage frame. Rigid arms radiate from this central member at the proper locations to which the fuselage rings are clamped (fig. 5–53). If other considerations permit the use of the internal type of jig, it has the advantage of leaving the surface free to apply the entire covering without changing jigs.

In fuselage designs where the longerons are let into the different fuselage rings at varying angles, the slots in the rings are sometimes cut oversize and squarely across to eliminate the necessity of setting up special jigs for slotting each ring and to facilitate laying the longerons in place. The triangular spaces remaining are then filled with small wedges coated with glue and driven in place.

5.4621. Gluing. The choice of glues for this work is limited to those of the cold-setting types. The spread should conform to previous recommendations for the type selected. The general tendency, however, will be to spread an excess so that the main precaution to be observed is to insure that all parts of the contact areas are completely covered. If the fuselage rings are of plywood, a part of the gluing will be end grain to side grain. If the contacting surfaces are not side grain to side grain, the practices recommended for the gluing of end-grain surfaces should be observed (see. 5.271).

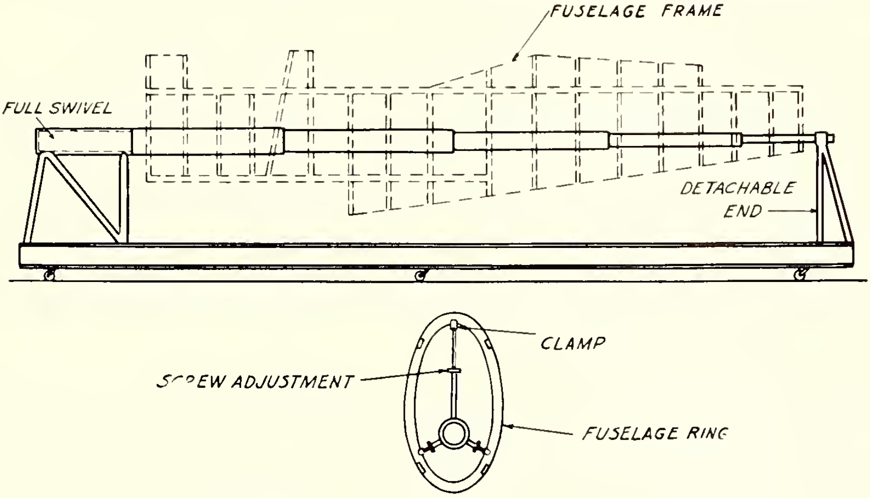

FIGURE 5–53.—Internal type jig for assembling fuselage frames.

5.4622. Pressure. In many operations, it is customary to fasten the longerons to the rings with screws that serve also to apply the gluing pressure. Frequently the joints will be in positions where clamps can be used and, wherever practical, their use is recommended.

5.4623. Conditioning Period. A conditioning period for the glue joints that greatly exceeds the time required to gain approximately the full strength of the glue is unnecessary; about 2 days at room temperatures is considered sufficient.

5.47. Application of Plywood Skins. Though cold-setting glues are largely used to attach plywood skins to the wings, fuselage, or control surfaces, it may sometimes be practical to use glues that require elevated temperatures for small assemblies that can be glued up and then moved into kilns where temperature and humidity can be regulated. The kiln procedure can also be employed to accelerate the curing of the cold-setting resin glues, which set more slowly at customary room temperatures.

Lamps have been used to accelerate the curing of the glue, but the advantage of their use is often open to question because of the relatively slow rate of heat transfer and the difficulty of obtaining proper humidification around the assembly. Resistance heaters applied as strips between the skin and nailing strips sometimes prove useful over limited areas where rapid curing of one joint may accelerate the assembly of a large unit.

The surfaces of the wing ribs, spars, and braces in the wing surface or of the fuselage rings, longerons, and braces in the fuselage surface should be true, smooth, and in alignment when the skin is attached. A common method of preparing the surfaces of the framing members is "floating" (sec. 5.658).

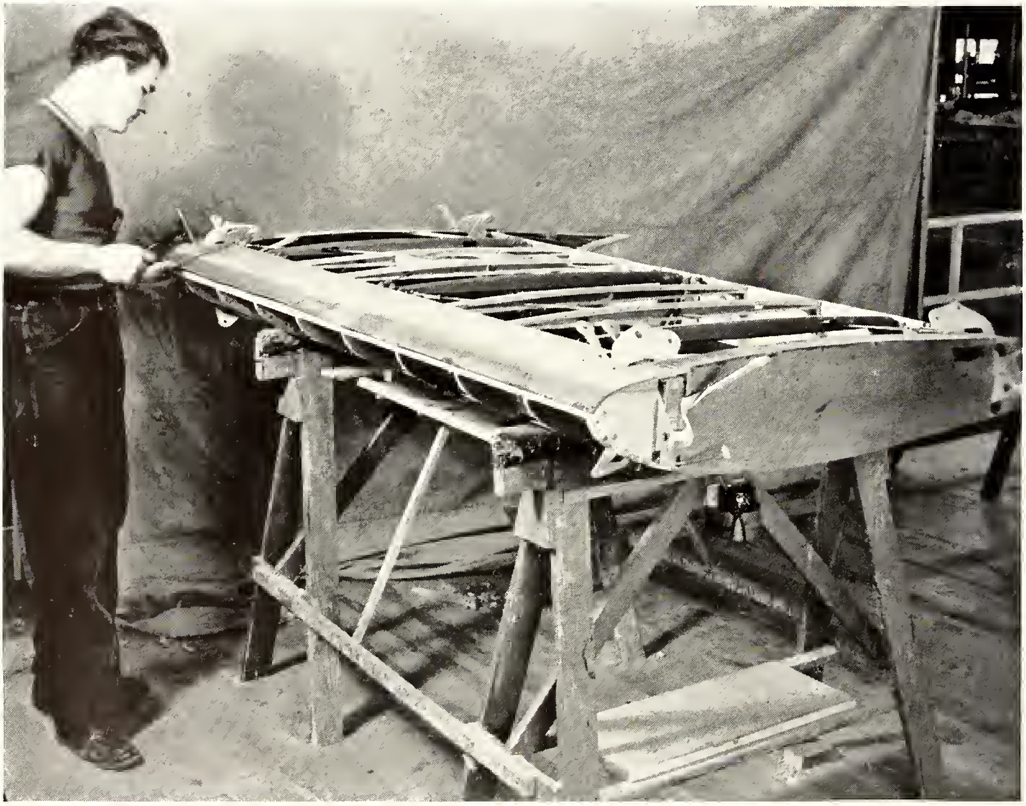

FIGURE 5-54.—Attaching flat plywood to the leading edge of a wing section.

It is desirable to prepare jigs to hold the wing or fuselage frames rigidly in position during the surfacing of the frame and attaching of the skin. The complexity of the jigs will vary, depending on the size of the assemblies and the method of applying the gluing pressures. If the gluing pressure is to be applied by nails and if the assembly is small, the jig may consist of merely the simplest support for the work (fig. 5-54). As the size of the assembly increases, the size of the jig must, of course, be increased.

5.470. Preparing the Skin. Before the actual operation of gluing the plywood to the frame begins, the plywood skin itself must be prepared for gluing. In some cases this may consist of merely cutting the plywood to size. Usually it will involve splicing two or more sheets in order to obtain the proper length. Plywood panels are ordinarily spliced by joining with scarf joints in separate gluing operations, although splicing with scarf joints may be done as a part of the operation of laying the skin. In either case, the precautions as to slope of scarf, gluing, and pressing that have been discussed previously should be observed (sec. 5.4102).

The amount of curvature may be so great that flat plywood sheets cannot be conveniently bent to the required shape during the operation of laying the skin (sec. 5.683). In such cases it will be found desirable to bend or preform the plywood sheet to approximately the desired shape before attaching it to the frame. In some cases it may be necessary to use shells of molded plywood rather than to attempt to bend a flat piece to the desired shape.

Occasionally the surface of the plywood may be glazed, show bleed-through of glue, or possess other characteristics that make it difficult to glue (sec. 5.27). Ordinarily these conditions can be remedied most easily by light sanding. The use of a paper no coarser than a No. 4–0 garnet is recommended for low-density species and no coarser than No. 3–0 garnet for high-density species. Only a small amount of the surface, usually not more than 0.001 inch, needs to be removed, and in no case should the sanding decrease the thickness of the face ply by more than 10 percent. If the aircraft manufacturer encounters trouble in secondary gluing to plywood surfaces, the subject should be considered with the plywood manufacturer and efforts made to eliminate the trouble at the source.

5.471. Attaching the Skin. It is important that all details be planned and arranged carefully in advance to avoid the danger of exceeding permissible assembly limits of the glue used.

5.4710. Glue Spread. The glue usually is spread on the contact surfaces of the frame and occasionally on both surfaces. Ordinarily, the spreading is done by hand and the natural tendency is to spread more glue than necessary, so that the main precaution is to insure that all surfaces are covered. Overspreading, however, is not good practice because it results in excessive squeeze-out, which may later be loosened and plug drain holes or grommets.

5.4711. Assembly Time. The interval between the start of the spreading operation and the complete application of the gluing pressure should conform to previous recommendations (secs. 5.24 and 5.404). In applying the skins to the larger assemblies for the first time, it may prove difficult to keep within these limits. This emphasizes the need for careful planning and suggests the training of crews on smaller assemblies before moving them to the larger and more complex units.

5.4712. Application of Pressure. The simplest method of applying gluing pressure is by the use of nails, either with or without nailing strips. If the nails are to be withdrawn later, the use of a nailing strip (fig. 5–55) is almost a necessity, but in some cases the nails are not withdrawn and no nailing strips are used. Nails set in nailing strips prepared in advance also speed the assembly work and reduce the danger of extended assembly periods. If nails are used, the spacing should conform to previous recommendations. For most plywood skins a spacing of approximately 1 inch is satisfactory, with one row of nails for each one-half inch in width of framing member and with the nails in each row staggered with respect to nails in adjacent rows. The length of the nails should be sufficient to reach at least three-eighths inch into the heavier supporting members, but they should not penetrate through the lighter supports. Some manufacturers have found a nailing machine of considerable convenience in preparing the nailing strips. The machine can be set for the desired nail spacing and adjusted merely to start the nails into the strips. A uniform spacing is thus assured, and one operator on a nailing machine saves the time of several in preparing the strips. Nailing machines have given some trouble in feeding the small nails, but one operator solves this difficulty by attaching a small magnetic vibrator to the feed box.

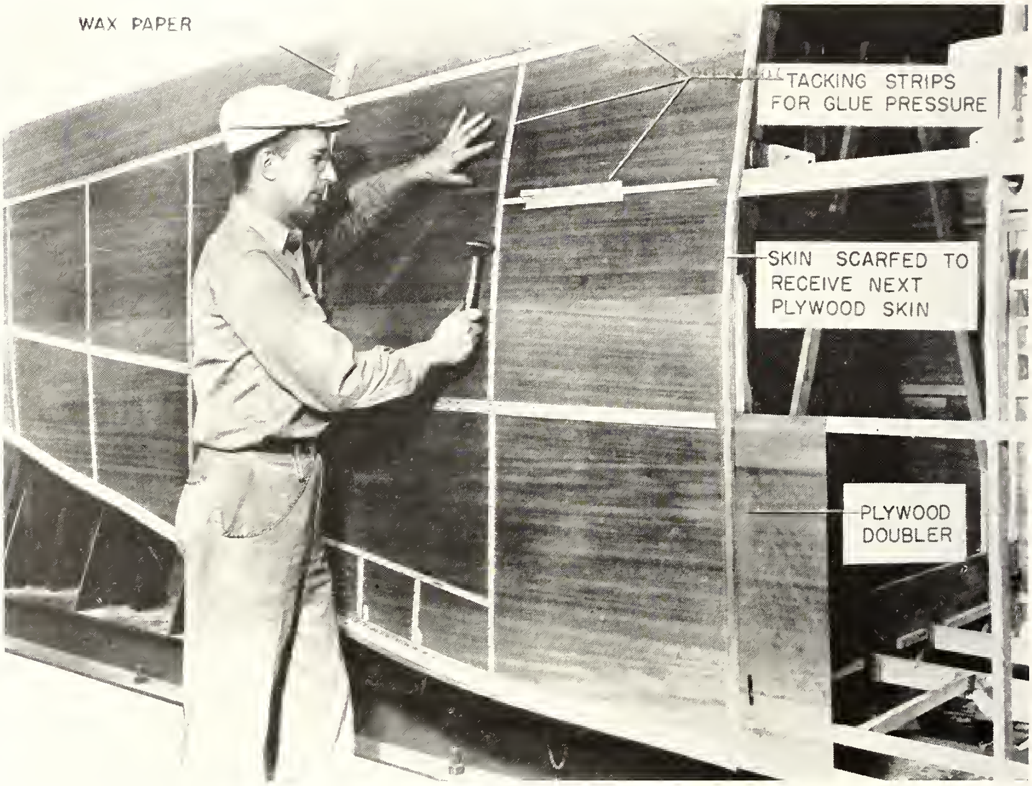

FIGURE 5-55.—Attaching the plywood skin to a fuselage frame.

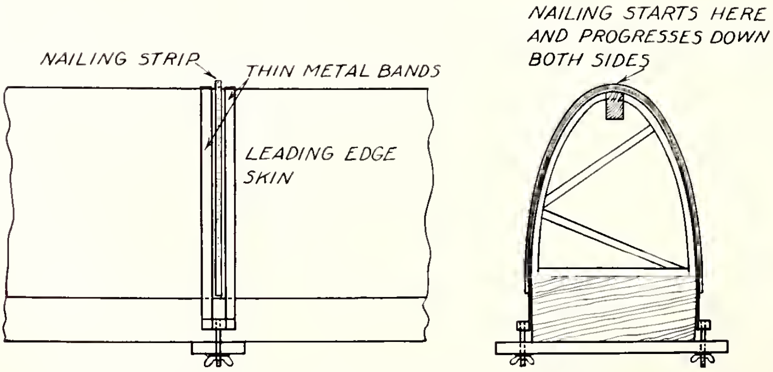

FIGURE 5-56.—Hold-down band clamp for nail-strip gluing of leading edge of skin.

A tension clamp, illustrated in figure 5–56, may be used to hold the leading-edge skin in intimate contact with the ribs while the nailing strips are applied. Cotton webbing approximately one-half inch wide is often used under nailing strips to facilitate removal of the strips and nails (fig. 5–57). A simple device illustrated in figure 5–58 has been found helpful in removing the nails and broken nailing strips from webbing so that it may be reused.

In nail-strip gluing the larger assemblies (fig. 5–55), the plywood skin is tacked lightly at one corner, then adjusted and tacked lightly in the opposite corner, inspecting carefully to insure that the skin is properly positioned. The first placement should be as nearly exact as possible, and moving of the skin over the frame should be reduced to a minimum. Otherwise the glue that has been spread on the frame may be scraped off and the amount remaining may be insufficient to form a good joint. In small assemblies (fig. 5–54) the cover may be attached first along one edge.

FIGURE 5–57.—Cotton webbing under nailing strips facilitates removal of the strips and nails.

When the plywood has been fastened lightly in its proper position, a nailing strip is laid over one of the principal supports and nailed in place, the nailing proceeding from the center outward to avoid wrinkles and bulges in the skin and to aid in flowing the glue to a thin film. The nailing strips should be carefully aligned to insure that the nails strike the support, and the nails should be driven firmly into place. Severe blows of the hammer that leave a definite crushed spot on the nailing strip should be avoided. Several light blows which leave the nail head flush with the nailing strip are recommended in preference to a single hard blow. In wing structures, the first nailing strips will ordinarily be laid over a spar. In the fuselage the first nailing strips may be over a central longeron or fuselage ring. The second nailing strip is usually laid over a support running at right angles to the first nailing strip. The successive strips are then nailed in place, always working from the area already attached, as from the center outward or from the top down, in order to permit the skin to assume the shape of the supporting frame without buckling and to assist in obtaining a thin, uniform film of glue (fig. 5–55). Enough strips must be used, of course, to cover the entire surface of members supporting the skin. Heat lamps are sometimes used to accelerate the setting of glu [illegible] assemblies of this type. When such lamps are used, it is important that humidity be controlled to prevent excessive drying of the wood. The use of heat lamps to accelerate setting of the glue is not recommended unless humidity is likewise controlled. A device for accelerating the setting of secondary glue joints on a wing tip is shown in figure 5–59.

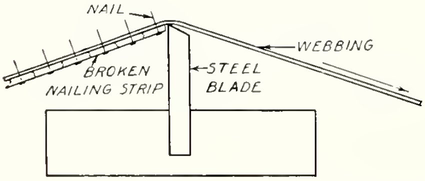

FIGURE 5–58.—Device for removing nails and broken nailing strips from webbing.

When the making of a scarf joint is a part of an assembly operation (fig. 5–55), cold-setting glues are suggested as the most suitable for the purpose. A nail-strip gluing technique is usually used. The size of nails and nail spacing will vary somewhat with different operations, but two rows of nails per inch of width is suggested, with a nail spacing as recommended earlier in this section. If rapid curing of the glue is essential to production schedules, it may prove convenient to accelerate the setting of the glue by the use of moderately elevated temperatures applied after the parts have been nailed in place. Resistance elements, often fastened in place by the nailing strip directly on the surface of the plywood, are suitable for the purpose, provided the time-temperature cycle used is regulated to prevent damage to the wood or glue. Lamps and warm rooms may also be used if provisions are made to control the relative humidity in order to prevent excessive drying and consequent moving of parts during the curing period.

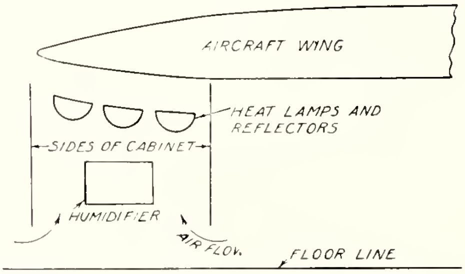

FIGURE 5–59.—Device for accelerating the setting of secondary glue joints by means of heat lamps.

The design of plywood skins for aircraft sometimes calls for joints to be made between skins of unequal thickness. Figure 5–60 illustrates two methods of forming these joints between the main wing skin and the leading-edge skin. Figure 5–60, *A*, shows a scarf joint in which the length of scarf is equal on both skins. The length of scarf should be at least 12 times the thickness of the thicker skin. Figure 5–60, *B*, illustrates a modified butt joint in which the thicker plywood is rabbeted to receive the thinner skin. This type of joint is less desirable, particularly for plywood wings not covered with fabric, as the finish is likely to fail over the butt joint. Neither joint should be relied on for the full tensile strength of the thinner plywood.

5.4713. Special Gluing Jigs. Several other methods of applying gluing pressure have been devised. Often these methods require more or less complicated jigs, and some are applicable to one particular operation but not to others. One of the simpler jigs is designed to apply gluing pressure to the plywood covering of the leading edge of a wing. It consists essentially of supports or cauls set in a metal frame in a position corresponding to the positions of the ribs in the leading edge. In operation, the preformed skin is first laid in place in the jig. The leading-edge frame, with the ribs attached to the spar and with the surface of the ribs coated with glue, is then laid in the formed skin and so positioned that each rib is bearing on a support or caul in the jig. Gluing pressure is obtained partially by applying pressure against the top of the spar. Pressure so applied reacts principally against the nose of the curve, while pressure against the sides is relatively low. Pressure against the sides is brought up to satisfactory magnitude by the use of clamps or other devices to exert an inward pressure on the two prongs of each support or caul. The supports are often lined with strips of rubber to provide a more nearly uniform distribution of pressure. If such a device is used, the gluing pressures should be calculated on the basis of the actual gluing area and they should be approximately 150 pounds per square inch or the maximum pressure that the frame will withstand, whichever is the smaller.

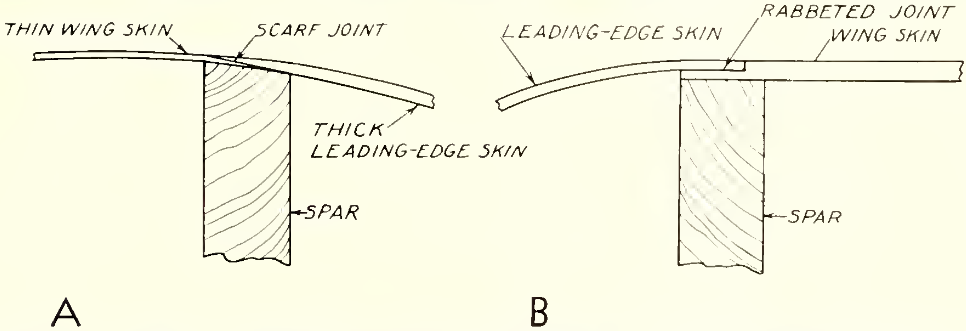

FIGURE 5-60.—Two methods of forming joints between skins of unequal thickness. *A*, scarf joint in which the length of scarf is equal on both skins. *B*, modified butt joint in which the thicker plywood is rabbeted to receive the thinner skin.

Another device for applying gluing pressure in covering wings is illustrated in figure 5–61, *A*. Its use requires the construction of a jig to hold the wing frame in place and to provide for the attachment of the metal pressing frame illustrated at the location of each rib. The gluing pressure is obtained by laying a caul, curved to the shape of the wing, over each rib and applying pressure by tightening the screws. The device is most suitable for assemblies in which the rib spacing is comparatively large and the wing ribs heavy.

Several types of gluing jigs employing heat and sometimes fluid pressure are being used to attach the skin to the framing members of wings and fuselages. Cross sections of two types, both utilizing fluid pressure and heat, are shown in figures 5–61, *B* and *C*, and 5–62. The jigs shown in 5–61, *B*, and 5–62 employ an extruded rubber tube which exerts pressure and supplies heat from steam passing through the tube. Pure steam is used, and there is, hence, a definite relation between pressure and temperature corresponding to that given in steam tables. Ten pounds of steam pressure at approximately 240° F. is reported to have been used to set a cold-setting, urea-resin glue joint under a $\frac{3}{32}$-inch plywood skin in about 10 minutes. The jig illustrated in figure 5–61, *C* uses air pressure and an electrical strip heater. This arrangement provides individual control of pressure and temperature to any desired level. A strip-heater temperature of 200° F. is reported to have been used to set a cold-setting, urea-resin glue line beneath a $\frac{3}{32}$-inch plywood skin in about 12 minutes.

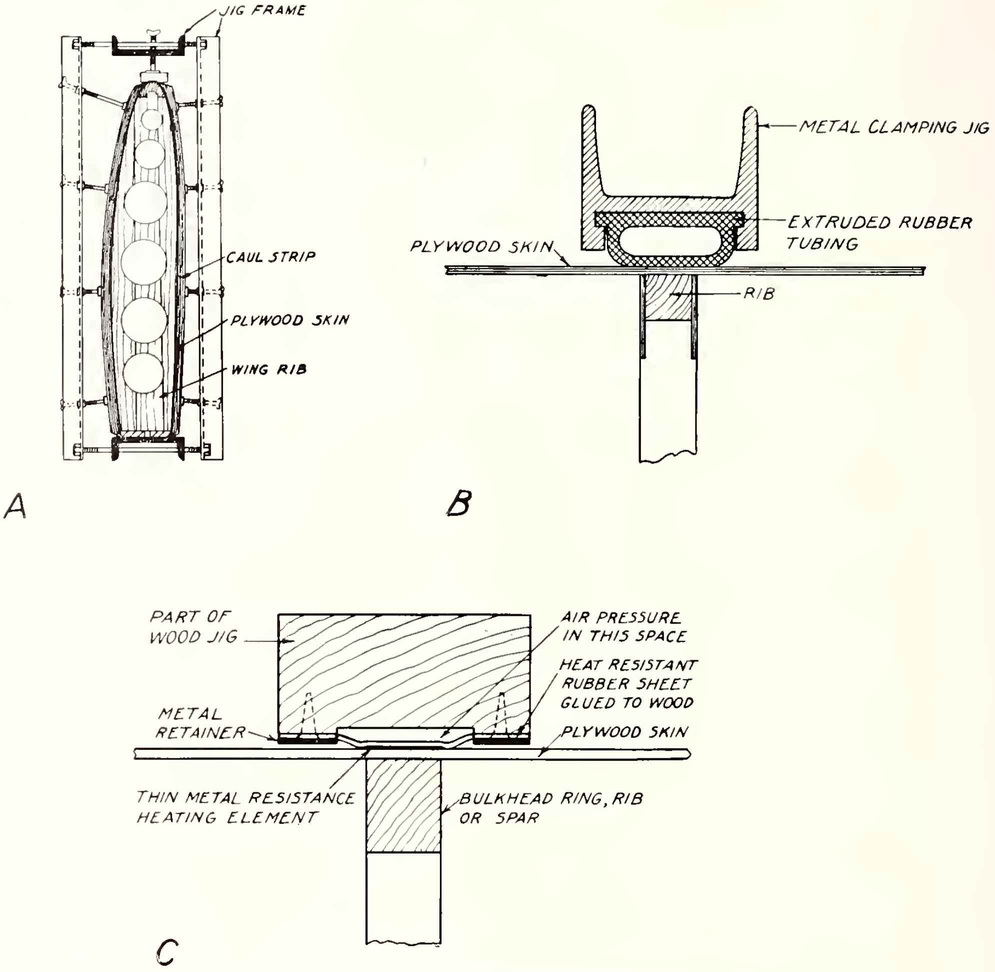

Figure 5-61.—Devices for applying gluing pressure and heat in covering wings.

5.4714. **Bag Pressure.** Another method of applying gluing pressure to frame assemblies involves the use of rubber bags and pressures that can be obtained by drawing a vacuum on the bag. In this operation the entire skin, preformed to approximate shape, is fastened lightly in place over the frame, the bearing surfaces of which had been previously coated with glue. A series of slats somewhat resembling the arrangement in a roll-top desk is laid over the work, with the slats running at right angles to the wing ribs. The entire assembly is then inserted in a rubber bag, the end closed, and a vacuum drawn on the bag. Since the area of the bearing surface of the ribs is small compared to the total area of the wing, the vacuum pressure will be multiplied several times on the bearing surfaces of the ribs and the amount of vacuum must be regulated accordingly. Over the spars or other members that are parallel to the slats, however, the pressure in pounds per square inch may not exceed that indicated by the vacuum, and additional pressure from clamps outside the bag may be necessary on these areas. The method is somewhat limited to constructions in which most of the framing members run in one direction and in which the bearing area of the frame is small compared to the total surface area.

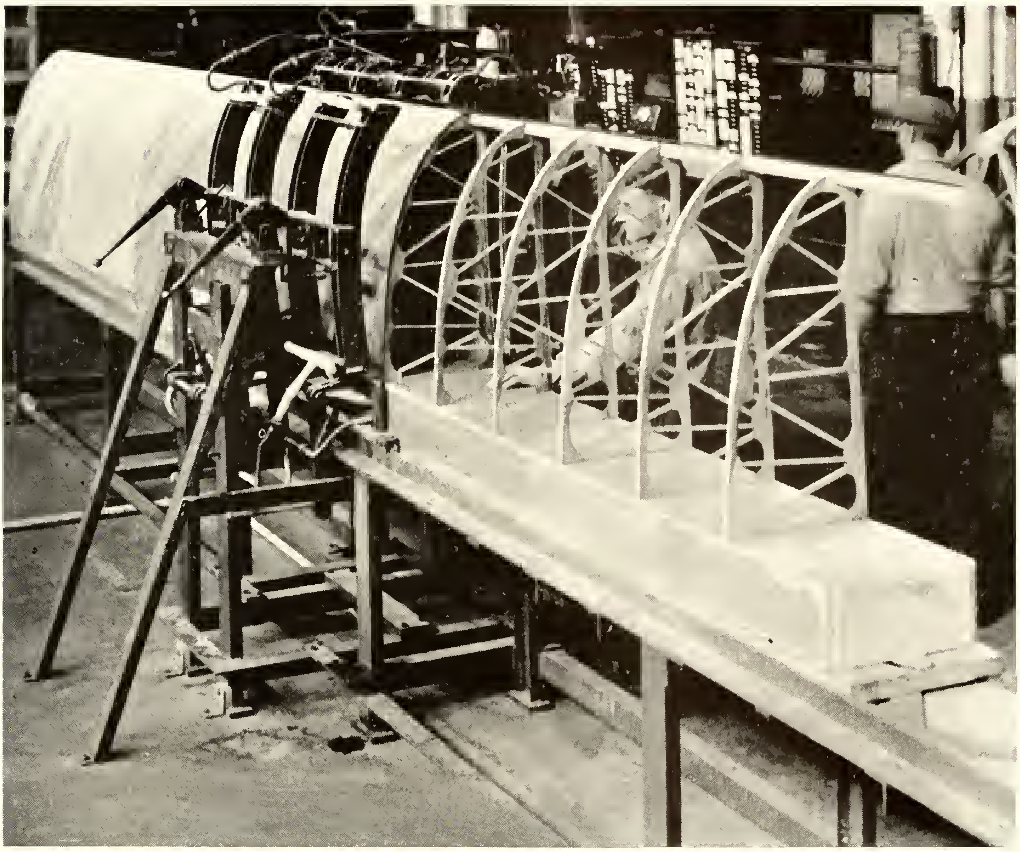

FIGURE 5-62.—Steam-heated pressure jig used to attach plywood skin to framing members.

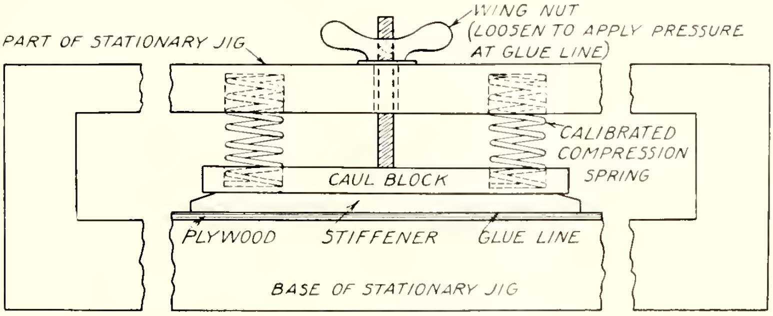

FIGURE 5-63.—Spring-loaded clamping device.

In applying the method it is essential, in order to prevent depressing the skin between ribs or other supports, that the slats be relatively stiff.

5.4715. Precautions Against Uncontrolled Pressures and Heat. In some special secondary gluing operations it is necessary to guard against the application of high uncontrolled pressures. Small, softwood members can easily be crushed by excessive pressure. Figure 5–63 illustrates a means sometimes used to apply controlled pressure to such small parts, the force being applied by releasing a compression spring. This type of clamp has the further advantage that the pressure will be relatively unaffected by a slight shrinkage of the wood due to loss of moisture if the glue joint is set rapidly by the application of heat.

All heated assembly-gluing jigs and special presses heated from one side only should be carefully checked before use, and at definite periods thereafter, to guarantee temperature conditions adequate to cure the glue. The most accurate and convenient method of making this check is to insert thermocouples in the glue lines in question, being sure that the glue line farthest from the source of heat is checked.

5.4716. Pressure Period. The gluing pressure should be maintained for at least 4 hours at ordinary room conditions if cold-setting glues are being used. The pressure period may be decreased if equipment is available to raise the temperature during the curing period. If nail-strip gluing has been used and the nails are to be removed, it is probably desirable to allow 6 hours at ordinary room conditions before the joints are subjected to the stresses incident to removing the nails.

5.4717. Final Conditioning. After the skinning operation is completed, the moisture added with the glue should be allowed to diffuse before the final sanding or surfacing preparatory to applying finish. Under normal room conditions, this will require 2 to 3 days, but the process may be accelerated by moderate heat so that an extended conditioning period may be unnecessary unless exceptional freedom from irregularities is essential.

5.5. TEMPERATURE MEASUREMENT.

5.50. General. For the measurement of temperatures, such as room or wet- and dry-bulb temperatures for humidity control, ordinary glass stem theremometers of good quality are entirely satisfactory as indicating instruments. The wick of a wet-bulb thermometer should be moistened with clean water (distilled if available) and whirled or held in a rapidly moving stream of air until the wet-bulb temperature reading has become constant. Wicks should be renewed before they become encrusted with mineral deposits.

Where room temperatures are critical, recording instruments are useful in adjusting controllers and in providing a permanent record. Various types are available, some of which can be moved from one department to another to check conditions within short periods of time.

5.51. Thermocouples. A number of temperature measurements can be made most conveniently with thermocouples, which consist of fine wires of two different metals, usually copper and constantan, for temperature measurements in processing wood. Constantan is a special alloy of very stable properties. When a loop is made of two such wires and the junctions of the wires are at different temperatures, an electromotive force is set up in the loop which is dependent upon the kinds of metal used and the difference in temperature between the two junctions. Differences in electromotive force, usually translated into a temperature scale, are obtained by a convenient portable potentiometer.

Thermocouples are especially useful for making temperature measurements in places inaccessible by other methods, particularly in glue joints and the like. They may also be used to check temperatures in various parts of dry kilns. The actual temperature measurement may be made at some distance from the point at which the thermocouple is located. Leads from a number of thermocouples may be brought to a central switchboard for reading (fig. 5–64).

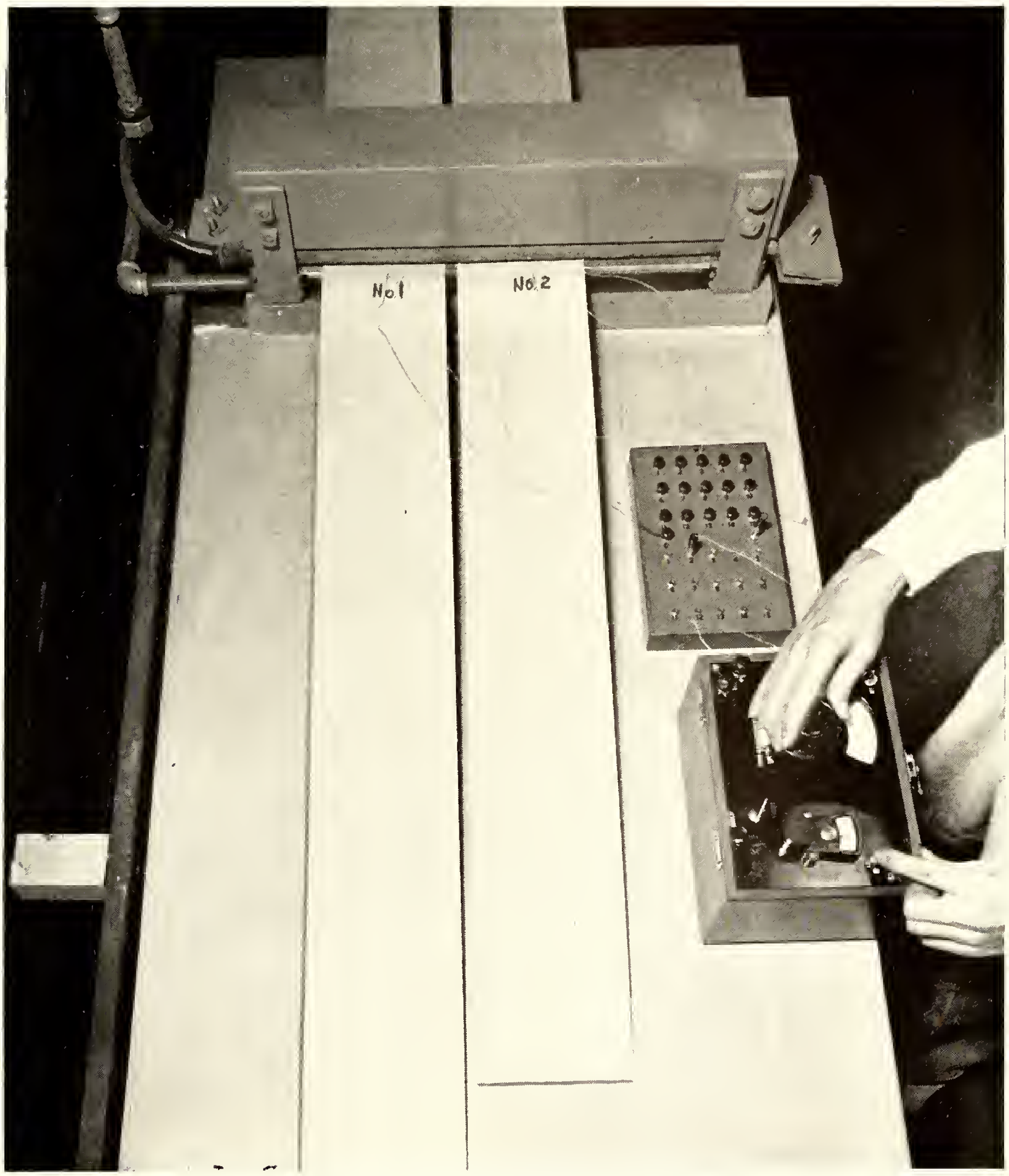

FIGURE 5-64.—Multiple switching arrangement for reading thermocouples. The board may be enlarged to accommodate any number of thermocouples.

Thermocouple wire is made from metals now difficult to obtain and since wartime uses of thermocouples have greatly increased, it is necessary to conserve the wire in every possible way. If a large number of thermocouples are to be read some distance away, a single or common constantan lead may be used for the whole group. Thermocouples can be made of fine wire (No. 30 or somewhat finer) and may be cutoff and left in the work without damage to woodworking tools or the mechanical strength of the parts being made. It may be obtained bare, enameled, or enameled and cotton covered.

Long leads may be avoided by the use of the thermocouple extension connection shown in figure 5–65. This device not only conserves thermocouple wire but affords a rapid means of connecting the potentiometer to the thermocouple. It has been found advantageous to cement the two wires together by stretching 20 or 25 feet or more of wire between two points and cementing them together with a rapid-setting nitrocellulose glue such as ordinary household cement. The cement is placed in a folded paper and the wires passed through the cement. The wires are separated for a short distance at the ends and then passed through a previously perforated paper board as shown at *A* in figure 5–65 and twisted as shown at *B*. *C* and *D* are finished connections with the copper loop through the paper on one side and the constantan on the other. The wire covering is removed from the exposed wire by lightly filing. A small wood pin is placed under the exposed wire at *D* merely to give it a little better elevation. An ordinary spring clip is used to make the connection as shown at *E*. The thermocouple wire is carried out to the jaws of the clip, wrapped closely around the jaws which have been previously flattened and cemented together with nitrocellulose cement. After the cement has dried the inside faces of the jaws are filed to expose the copper and constantan. Both the connection and clip should be marked so that the latter may be properly attached. Since the wires are directly connected no error can be introduced by handling the clip.

Most portable potentiometers are equipped with temperature-compensating devices which make unnecessary the use of a constant temperature at the cold junction. The use of these instruments is not difficult, but a few points should be borne in mind by those who have not had experience with them.

1. The working voltage should be adjusted with the standard cell when measurements are to be made and thereafter at intervals frequent enough to maintain a uniform working voltage. Instructions for making this adjustment usually accompany the instrument.

2. The potentiometer should be used in a protected place where the surrounding temperature will be as uniform as possible. Radiant heat from hot presses, ovens, or direct sunlight should be avoided since the compensating device may not function accurately under such conditions. Likewise, if an instrument is taken from a location at one temperature to one at another temperature, the instrument should be allowed to come to the approximate temperature of the space before it is used.

3. The covering and enamel on the wire should be carefully removed where the junction is to be made. This can be done easily by holding the wire in a clamp and pulling the ends through fine sandpaper, after which the wire ends should be wiped clean and twisted tightly together. For ordinary use the twisted tip will give a satisfactory contact; if the thermocouples are to be used a long time in an inaccessible place, however, they should be dipped in hot solder to make a permanent contact. A long twist is not necessary or desirable, as the temperature measured is that at the point where the two metals first come in direct contact outside of the loop.

4. The thermocouple junction at which the temperature is to be measured should be placed in a critical position in the work and the leads carried out to a point where a connection can be made or to a central switch if a large number of measurements are to be made.

5. Only the kinds of wire and the calibration for which the potentiometer is designed should be used with it.

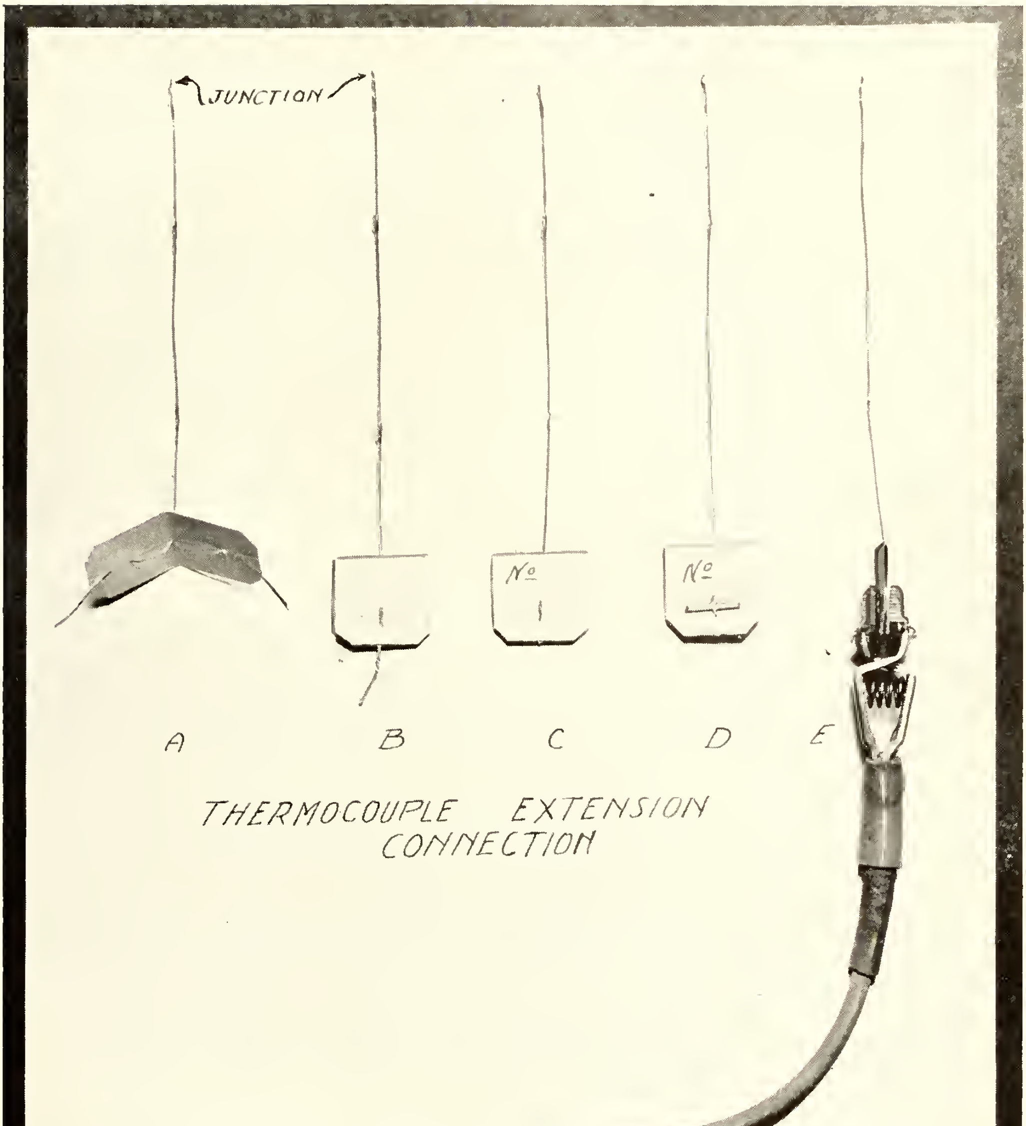

FIGURE 5-65.—Thermocouple connection extension to provide a rapid means of making connections for temperature readings.

6. Where strip heaters are used the thermocouple junction should be in the glue joint and so arranged that the wires will not come in contact with the strip heaters.

7. Surface temperatures may be measured by recessing the thermocouple into the surface and securing it in place by pressure or by means of a suitable adhesive.

8. The use of jacks and clips of different metals from the thermocouple wire for switching purposes will not introduce an error if both connections to the thermocouple wire are at the same temperature. If one end of a clip is connected closely to a thermocouple wire in a heated part, however, an error in the temperature reading will result.

5.6. MACHINING, BENDING, AND OTHER WOODWORKING OPERATIONS.

5.60. General. Among the important classes of properties that affect the general utility of any wood are its machining properties, which embrace all woodworking operations. In these, as in other classes of properties, different woods vary widely and a given wood may give good results in some operations, fair in others, and poor in still others. The "workability" of any wood, therefore, cannot be judged by one operation, but depends rather upon the summation of all of them. In any operation there are several factors, both in the wood itself and in the machine, that affect the results, and these results may be good or bad depending upon the conditions under which the work was done. Some woods machine well under a relatively wide range of conditions, while others are handicapped by the need of exacting techniques if good results are to be obtained (*5–31*).

If the machining operation involves the preparation of a surface for gluing, the stock should be conditioned to the proper moisture content for gluing before the surface is machined (sec. 5.28). The two pieces making up a scarf, for example, should be as nearly as possible at the same moisture content at the time of gluing; a variation of approximately 2 percent is the maximum permissible. Any machining that is done following gluing should be preceded by sufficient conditioning to obtain a uniformly distributed moisture content in the member that will approximately equal its average moisture content in service (sec. 5.010).

Most of the machining operations required in fabricating aircraft parts can be carried out on equipment that is readily available in wood-working plants. In many instances, standard equipment can be used directly; in others, it can readily be adapted and supplemented by jigs and templates for the making of such parts as spars, ribs, wing-tip bows, and the like.

Some operations, on the other hand, do require special procedures, either in the way of specialized equipment or special techniques in manufacture. Such operations are described in greater detail in the following paragraphs, and emphasis is placed upon the points requiring particular attention.

5.61. Cutting Scarf Joints. The use of some means of joining wood together to form long, continuous members in the grain direction is necessary whenever the length desired is such that it exceeds that commercially available in a single piece, or is desirable from the standpoint of using short lengths of otherwise good material. This applies to either solid wood or plywood parts.

The most satisfactory means for accomplishing this purpose, particularly for solid wood, is a properly made and glued scarf joint. Scarf joints have been successfully made at various slopes ranging from 20 to 1 to as steep as 8 to 1. In general, other conditions being equal, the steeper the slope the less waste in the cutting of the scarf, but the more difficult its gluing and the weaker the resulting joint.

5.62. Scarfing Solid Stock. The most important single item involved in the making of a scarf joint is the machining of the scarf surface. If the two scarf surfaces have the proper slope and are smooth, true, and accurately fitted, the gluing can be done without difficulty. If the surfaces are not accurately fitted, joints of the quality essential in aircraft cannot be expected.

The slope of the scarf may depend on how highly the part is stressed, but a slope not steeper than 1 in 15 should be used for all stressed parts (sec. 2.410).

The slope of grain with respect to the scarfed surfaces may be greatly increased or decreased if the material to be spliced is cross-grained, depending on whether the cut is made across or with the grain. All scarf cuts should be made in the general direction of the grain, as illustrated in figure 5–66, since the greater the angle the grain makes with the scarf the more difficult the surface is to glue (sec. 2.4111).

The laminations in the solid wood members of aircraft usually requiring scarf joints are neither unusually thick nor wide; consequently, the scarfs can generally be prepared on some standard woodworking machine by the use of special jigs. Some of the most commonly used methods are described here.

5.620. Planer. Figure 5–67 shows the cutting of a scarf joint on an ordinary single-head cabinet planer. As the stock passes through the planer it is guided and held at the proper angle by a heavy, three-part supporting block, preferably made of hardwood. The central portion of the block is horizontal on the bottom, beveled on the top to the desired slope, and is as wide as the material being scarfed. To prevent the stock from moving sidewise as it passes through the planer, two rails, equal in height to the greatest thickness of the beveled central portion, are bolted to it, forming a channel with a sloping bed.

The bed of the planer is set low enough to allow the guide block barely to pass through. The material to be scarfed is laid on the beveled guide, as illustrated, and fed through the planer. By one or more trips, depending upon the thickness of the lamination and the power on the cutting head, an accurate scarf can be cut. To reduce the number of passes, the scarf may first be sawed to approximate shape (sec. 5.625). Any tendency of the stock to slide may be prevented by placing sandpaper, rosin, or small metal spurs on the beveled surface of the jig. The spurs may simply be small nails partially driven and sharpened on the protruding end. It is important to place the piece in such a manner that its end coincides with the end of the sloping surface of the jig, so that the scarf may taper off to a feather edge. It is necessary to support the free ends of long pieces so that the work lies tightly against the slope of the jig and does not bow up, causing the slope of the cut to change.

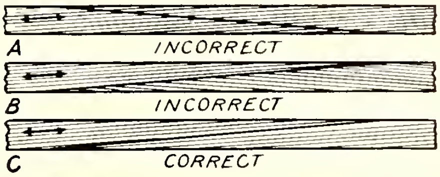

FIGURE 5–66.—Consideration of grain direction when making scarfing laminations with cross grain, the slope of grain in the laminations being within the permissible limitations of specifications. Arrows indicate grain direction.

5.621. Shaper. If the stock to be scarfed is less than 5 inches wide and not too long, the operation may be carried out on a vertical spindle shaper equipped with straight knives (fig. 5–68). In this instance, the jig is arranged so that the guide runs against the collar of the shaper head and the piece being worked is held at the desired angle to the path of travel. The piece being scarfed is securely clamped to a jig cut to a large radius of curvature to prevent lifting of the end of the piece. As in the planer operation, the final cut should be light, movement (or slippage) of the piece with relation to the jig should be avoided, the piece should be placed to taper off to a feather edge, and the free ends of long pieces should be supported.

5.622. Jointer. A hand-feed jointer having long tables may be used to produce accurate scarfs when equipped with the proper jig. One suggested type of jig is shown in figure 5–69, *A*. Here again it is important that the jig be equipped with proper and adequate clamps to hold the piece firmly in place. The scarf cut should be made in at least two trips over the head, the final one being very light.

5.623. Tenoner. On thin, but relatively wide, material it has been suggested that a single-end tenoner may be quickly converted into a satisfactory machine for

FIGURE 5-67.—Cutting a scarf joint on an ordinary single-head cabinet planer.

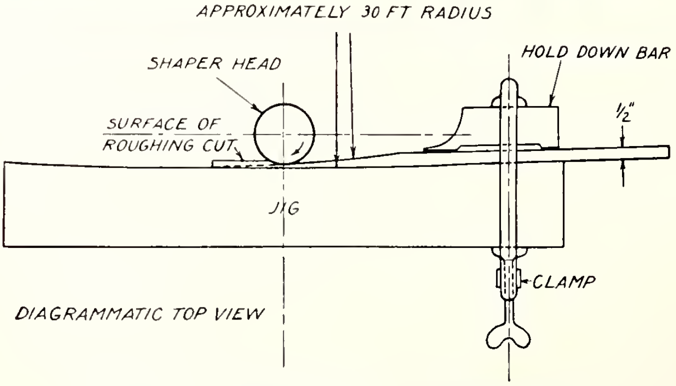

FIGURE 5-68.—Scarfing operation on a vertical spindle shaper.

cutting scarf joints. A sketch of this scheme is shown in figure 5-69, *B*, as applied to a tenoner having nontilting heads. If the head can be set at an angle, the piece may be held in a horizontal jig. Tenoners of this type have heads not longer than about 7 inches; therefore the maximum thickness of material on a 15 to 1 scarf would be about three-eighths inch. Since the travel of the cutters is across the grain of the wood, considerable care is required to produce a surface of the requisite smoothness. The spiral knives with which tenoner heads are equipped are advantageous in this respect. A "back-up" block may be necessary to prevent splintering as the knives leave the cut.

5.624. Vertical Cutter-head Scarfing Machine. A special machine for cutting scarf joints on laminating stock is illustrated in figure 5-70. The stock is held rigidly on a stationary vacuum bed while the cut is made with a high-speed traveling cutter head. The cutter head produces a scarf cut that resembles a smoothly sawn surface.

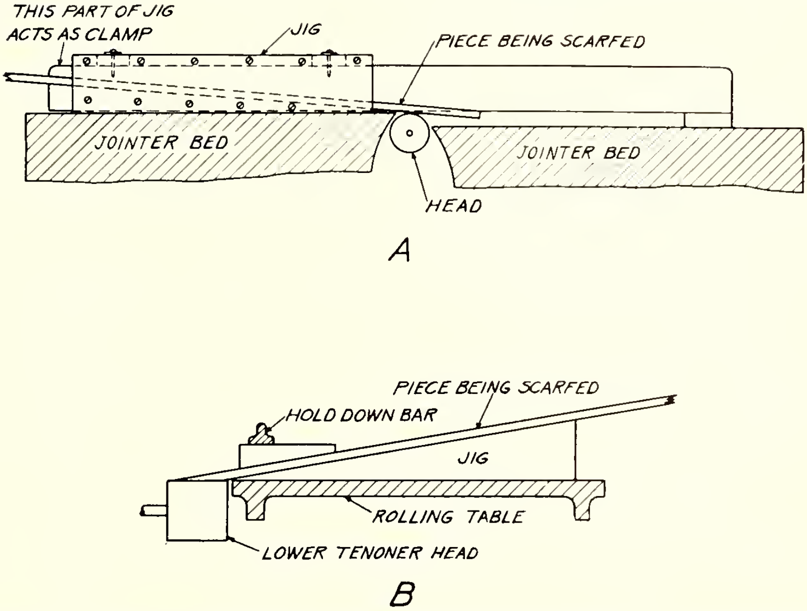

FIGURE 5-69.—Scarfing. *A*, jointer. Stock is clamped on inclined jig and passed over jointer head. Final pass is light, to produce straight cut; *B*, single-end tenoner adapted with beveled jig and hold-down bar for scarfing.

5.625. Saws. Scarf joints can, of course, be cut with saws, but to produce sawed surfaces that will form a good joint requires unusually good equipment, maintenance, and operation as well as careful inspection. The degree of care required to produce satisfactory gluing surfaces directly from a saw is not ordinarily maintained in production operations, and the average sawed surface is likely to be "fuzzy" and rough, with a considerable amount of torn fiber which tends to produce weak joints (see. 5.21). Sawing of the final gluing surfaces should be avoided wherever possible.

5.63. Scarfing Plywood. Preparing scarf joints in plywood offers greater difficulties than in solid wood because some of the plies run at right angles to the direction of the cut. The pieces are too wide for most planers and the cutting, consequently, is usually done at right angles to the grain of the faces, adding to the difficulties of feathering off the scarf to a fine edge. Scarf joints in plywood accordingly are sometimes prepared with hand tools. The scarf cut, which should have a slope not steeper than 1 in 12, may be made with a plane, electric sander, sandpaper block, wide

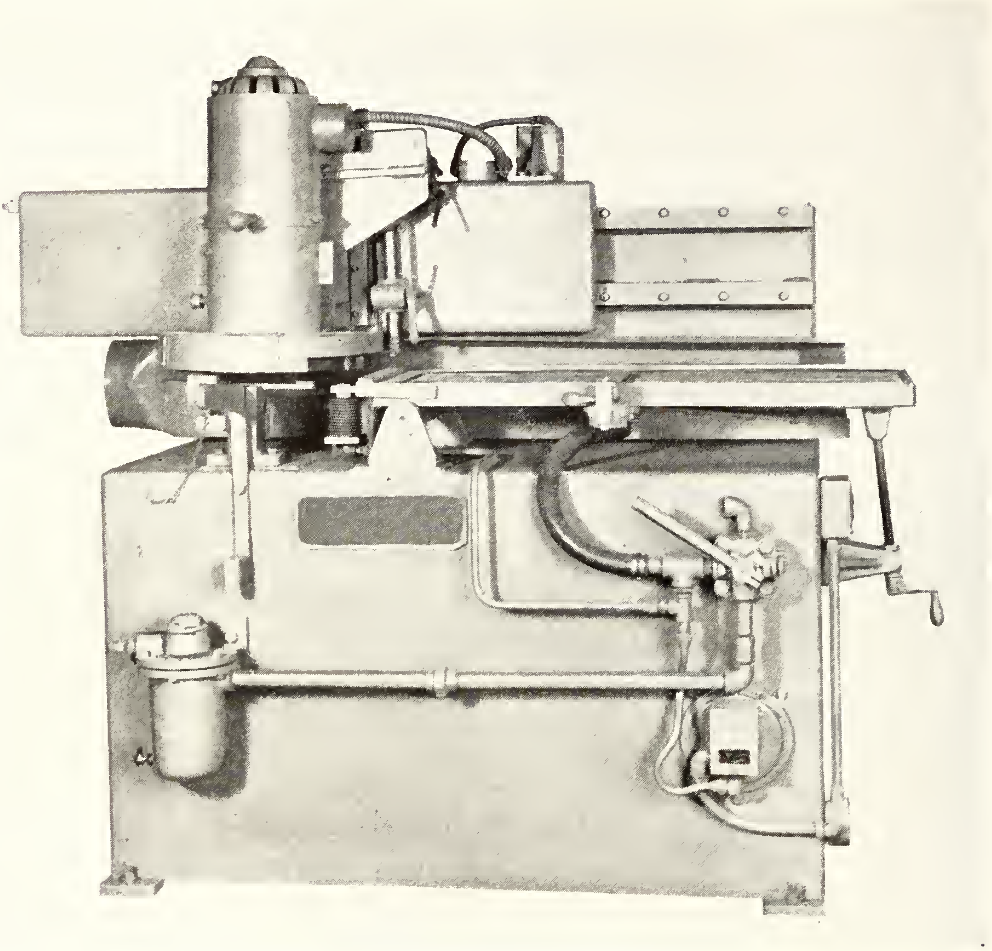

FIGURE 5-70.—Vertical cutter-head scarfing machine.

spokeshave, or scraper after first firmly clamping the plywood to a solid flat surface. In thick plywood, the rough cut is sometimes made with a table saw and the scarfed surface finished by hand.

5.630. Hand Plane Scarfing Device for Thin Plywood and Veneer. A hand plane may be converted into a manually operated scarfing tool by means of a suitable guide as illustrated in figure 5-71, *A*. For cutting across the grain, however, it is necessary to grind a slight back-bevel on the blade as indicated in figure 5-71, *B*. It is also important to grind a perfectly straight cutting edge at right angles to the side of the blade instead of the customary slightly curved cutting edge. This device operates most satisfactorily on one-sixteenth- to one-eighth-inch plywood. The maximum length of scarf is limited by the width of the blade, and seldom exceeds about 2½ inches. A shorter scarf may be made by the proper adjustment of depth and angle of the blade (*a* and *b* respectively in fig. 5-71, *A*). The metal guides (*c* of fig. 5-71, *A*) between which the plane operates prevent lateral movement.

5.631. Traveling Cutter-head Scarfing Machine. One type of scarfing machine which employs a traveling cutter head to cut scarfs on plywood panels is shown in figure 5–72. This is not a standard machine but was specially built, perhaps from the parts of a veneer jointer, to perform the scarfing operation. The maximum thickness of plywood which it will cut is determined by the length of the cutter head and the minimum thickness by the effectiveness of the hold-downs. These limits are probably about three-fourths and one-sixteenth inch respectively.

5.632. Saw-scarfing Machines. Another special scarfing machine in which a large heavy saw cuts the scarf is shown in figure 5–73, *A*. This is also an adaptation of a veneer jointer. The limits of this machine are about the same as for the traveling cutter-head machine, and the accuracy and smoothness of the cut depend largely upon effective hold-downs and proper saw condition. Frequent sharpening of the saw and constant attention to the surfaces produced are necessary to assure satisfactory surfaces for gluing.

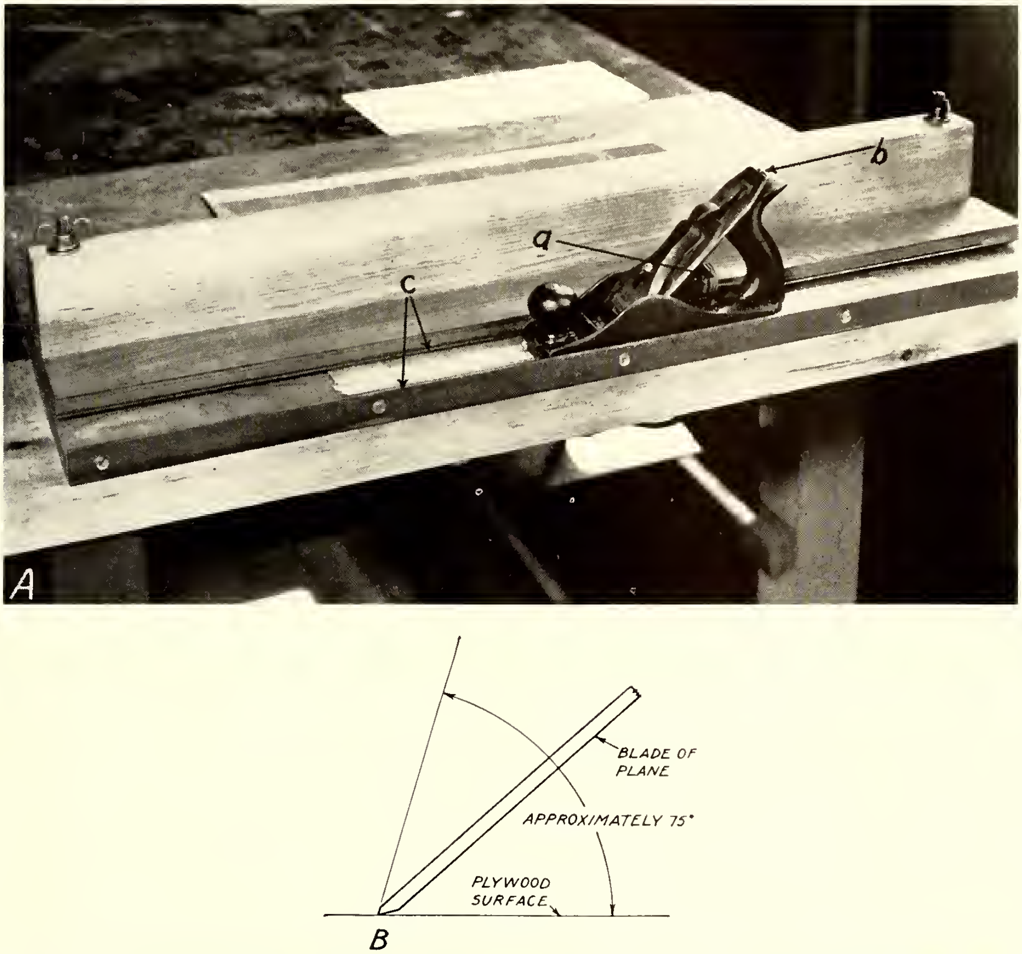

FIGURE 5-71.—Hand plane for scarfing thin plywood and veneer. *A*, arrangement for cutting a scarf; *B*, detail of cutting angle. The back-bevel of the plane blade should make an angle of approximately 75° with the bed of the plane.

A heavy-duty, slow-speed, vertical-spindle shaper can be converted into a satisfactory scarfing machine for plywood as shown in the diagrammatic sketch, figure 5–73, *B*. The knife collars are replaced by large stiffening collars for the saw. By building an adequate sliding table of wood framing, the plywood can be guided past the saw. Adequate and effective hold-downs in front of and following the saw are important in obtaining successful results from this machine. Saws used for scarfing should be of heavy gage and it is advisable to side-joint the teeth lightly to assure smooth, uniformly cut surfaces.

5.633. Sander-drum Scarfing Machine for Thin Plywood and Veneer. A narrow traveling sander drum can be used for scarfing plywood and veneer (fig. 5–74). When properly designed, this type of machine is capable of making accurate scarf cuts on thin plywood and veneer at all angles of grain. Machines of this type have been used on plywood as thin as $\frac{3}{100}$ inch and on plastic sheets $\frac{1}{100}$ inch to $\frac{1}{16}$ inch in thickness. The practical upper limit of thickness is about $\frac{1}{8}$ inch. The proper grade of sandpaper to use depends on the thickness and species of wood or the type of plastic sheet to be scarfed, but in general the thinner panels require finer paper. In no case should felt or other soft back-up material be used on the drum under the sandpaper, as such material tends to produce rounded edges and inaccurate scarfs. The drum should be of some hard, stable material, such as metal or plastic. The use of any type of a sanding drum to make complete scarf cuts on relatively thick panels is impractical because of the large amounts of material that must be removed in the form of sander dust. If most of the material is removed by some type of cutter head or saw, however, the finishing cut may be done accurately on a sanding drum.

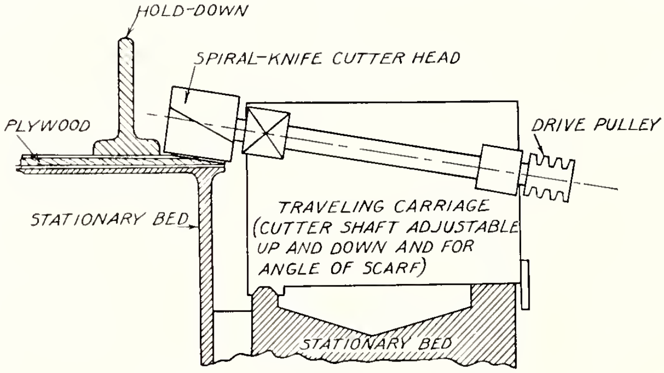

FIGURE 5-72.—Traveling cutter-head scarfing machine.

5.634. Sander-drum Scarfer for Veneer Strips. Strips of thin veneer have been scarfed by the use of a small diameter sanding drum and a movable clamping jig, as indicated in figure 5–75. The accuracy of this type of cutting device depends on the flatness of the veneer and the precision of the drum and the alinement guides.

5.635. Rotary Planer Scarfing Device. Another scarfing device which in principle is quite similar to figure 5–75 is shown in figure 5–76. The veneer or plywood being scarfed is passed under a small cutter head, sometimes called a "rotary planer." To insure that the end of the piece being cut is held down, an additional narrow hold-down is provided at the end. The extension illustrated in figure 5–76, *B*, is usually left on to protect the feather edge until the piece is ready for gluing, when it is easily broken off by hand.

5.64. Routing of Spars. Frequently, solid or laminated spars are rectangular in cross section, or are merely beveled top and bottom, but to reduce weight, may be routed. Three types of routed spars (fig. 5–77) are commonly employed:

a. Constant cross section, **I** or C in shape.

b. Constant depth, but routed in portions of the length to form **I**- or C-shaped cross sections with full-width flanges.

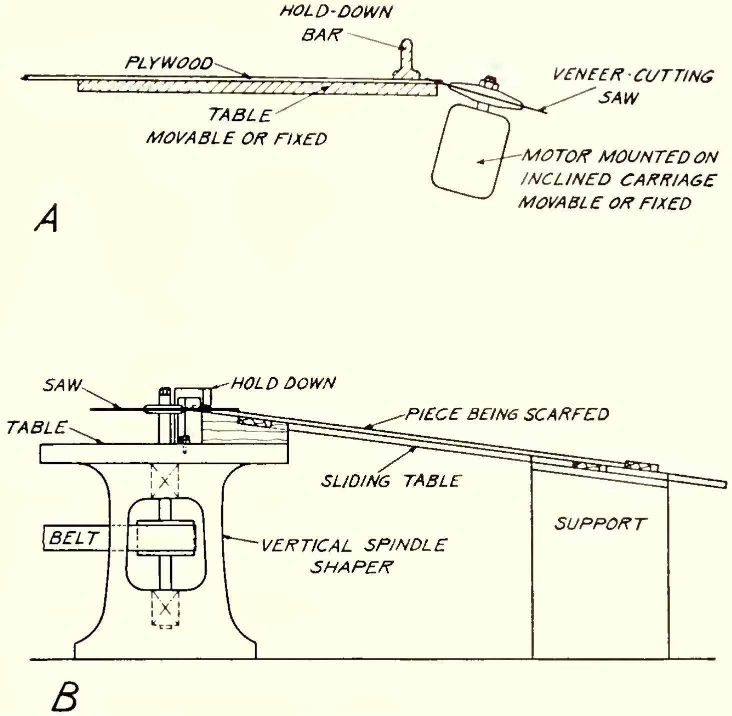

FIGURE 5-73.—Special saw-scarfing machines. Plywood is held rigidly in position on table by hold-down. Scarf is cut by moving table past saw (*A*), or by moving saw past table (*B*). Tilt of saw or table determines slope of scarf.

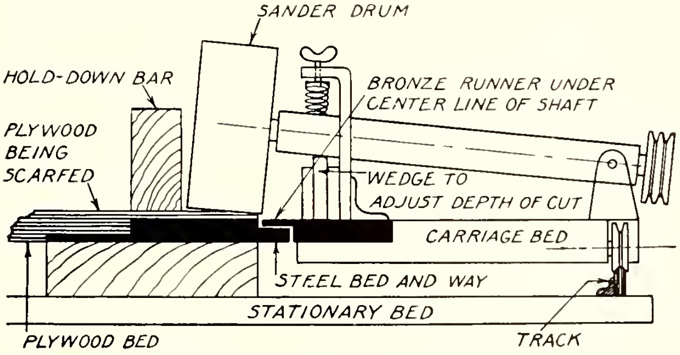

FIGURE 5-74.—Sander-drum scarfing machine for thin plywood and veneer

c. Variable depth, with or without webs partially cut away, as in (*b*). Type (*a*) is readily formed on a molder or shaper. Types (*b*) and (*c*) are conveniently formed on a router, with one bit of the proper profile for the edges and another bit for removing the central portion of the cut-out.

5.65. Beveling and Profiling Spars, Spar Flanges, and Similar Parts. During manufacture, spars, spar flanges, and similar parts are made slightly oversize, and receive their finished shape—profile and bevels— in a final shaping operation which leaves them ready for the assembly of ribs or other contiguous parts. Two principal methods are employed:

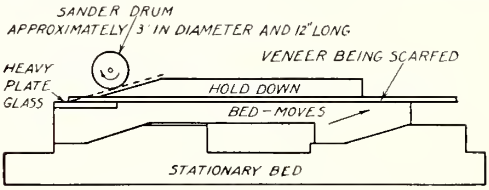

FIGURE 5-75.—Sander-drum scarfer for veneer.

(1) Part stationary on jig table; cutting done by tools moving along edges.

(2) Cutting tools stationary; part moved in frame past cutters.

5.650. Spar Profiling with Band Saw and Shaper. The method in which the jig table is stationary is applicable to spars of all sizes, but is especially useful for large members which are heavy and awkward to handle. These are clamped to a rigid stationary table whose top is a template of the shape required to form the profile of the spar.

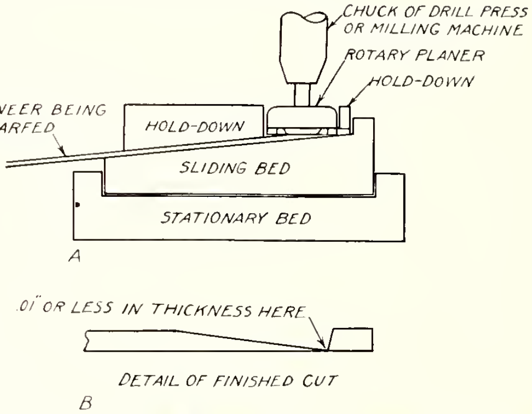

FIGURE 5-76.—Rotary planer scarfing machine for veneer and thin plywood.

Cutting is accomplished by band saw and shaper, as shown in figures 5-78 and 5-79. In both instances the tool is carried by two wheels running on a rail, as shown in the figures, and is guided by a wheel or collar running against the edge of the template. The weight of the tool keeps it in position while the operator moves it forward. An initial rough cut is made by the band saw, which cuts the profile and bevels the edges to approximate shape. The finishing cut is made by the shaper.

The amount of bevel imparted to the edge of the spar depends upon the tilt of the cutting tool, which in turn depends upon the lateral position of the rail with respect to the template. If the rail is situated a generous distance below the level

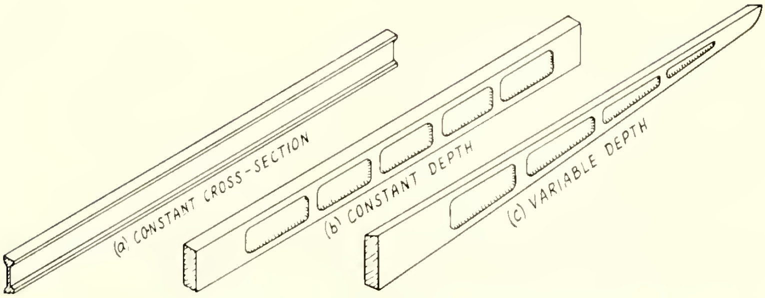

FIGURE 5-77.—Three common types of routed spars.

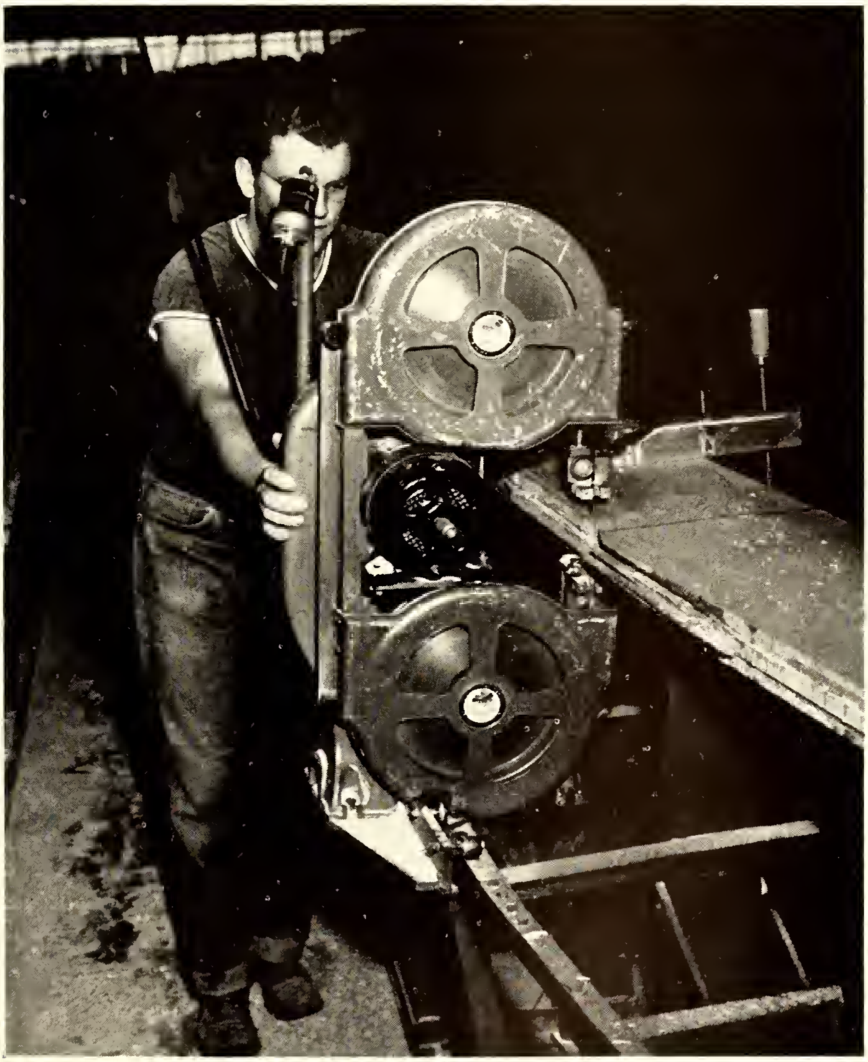

FIGURE 5-78.—Rough cutting profile and bevels on spar by band saw moving on template table and rail.

of the template, small deviations in its alinement have an inappreciable effect upon the bevel.

Although this idea has been developed principally for profiling and beveling spars, it is evident that it could be adapted to performing the same operations on other parts, such as fuselage rings.

5.651. Contour Planing of Spar Flanges. Spar flanges sometimes require machining to specially curved shapes on the surfaces to which filler blocks and spacers are later attached. This operation can be accomplished quickly and accurately on a specially built traveling-head contour planer. One design is shown in figure 5–80. The planer head passes lengthwise over the flange and cuts while moving in either direction. The supporting carriage rides on two straight ways, while the vertical movement of the cutter head is controlled by a roller running on a third track, which is contoured to produce the proper flange shape.

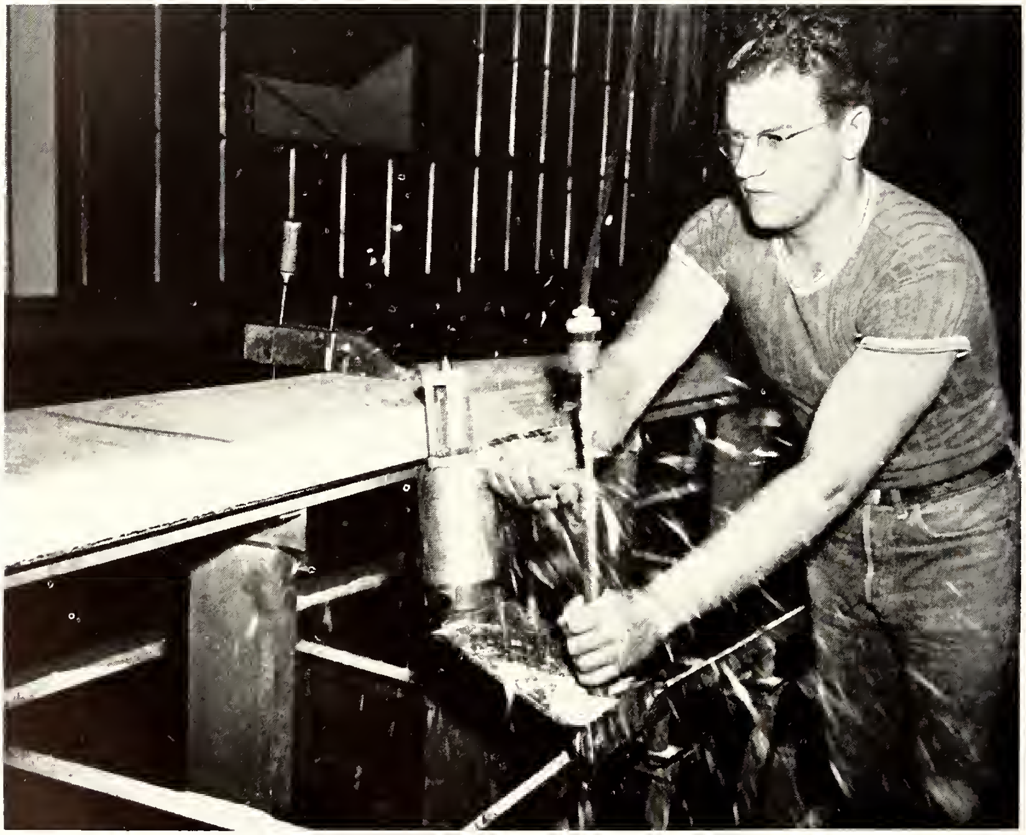

FIGURE 5–79.—Finish-cutting profile and bevels on spar by shaper moving on same template table and rail illustrated in figure 5–78.

5.652. Spar Profiling on a Jointer. Another method of spar profiling employs a jointer and a frame in which the spar is carried across the jointer head, imparting the proper bevel and profile to the top or bottom of the spar as it moves along.

The frame consists essentially of two track bars, two fillers, end blocking, and bolts. The track bars are boards cut to the required shape and fitted with steel tracks approximately ⅛ inch thick and 1 to 1½ inches wide. Track bars are clamped against the sides of the spar by bolts which pass through existing holes in the spar. Tapered fillers are placed between the spar and the track bars to maintain a constant distance between tracks. The method is illustrated in figure 5–81, which shows the frame assembled on the spar, sections through the assemblage at three points (fig. 5–81, *B*), and the assemblage in position on the jointer.

Rollers or curved guide plates on which the steel tracks move are attached to the frame of the machine. Their height is adjustable so that they can be raised for roughing cuts and then lowered to a stop for the final finishing cut. In operation, the profiling assemblage is simply pushed from end to end past the jointer, which automatically cuts the proper bevels and tapers. The final curved cut at "D" is not included, but is later formed by hand.

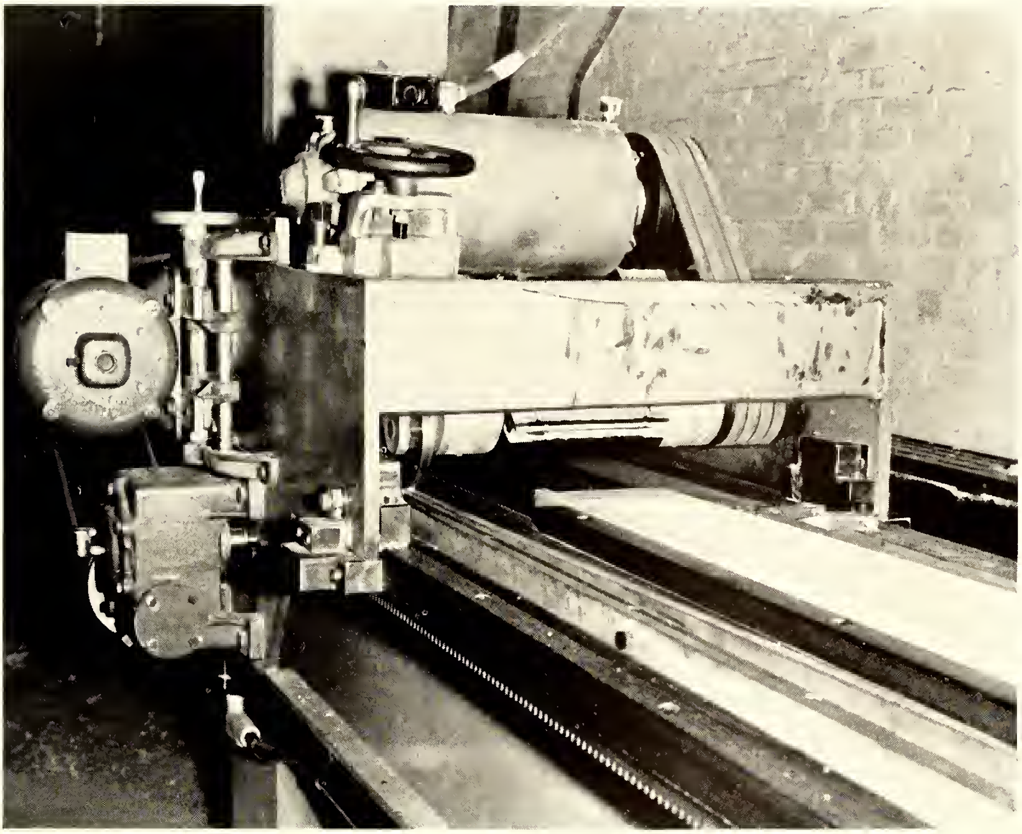

FIGURE 5–80.—Traveling-head contour planer.

If for the final cut the guides are in a position concentric with the jointer head, the cut will be correct regardless of whether the spar is kept approximately level.

With properly shaped and positioned track bars, constant or varying bevel can be cut. One set of track bars can be used to guide the cutting on both edges of the spar.

5.653. Shaping, Beveling, and Profiling of Ribs, Wing Frames, and Fuselage Frames. Edges of ribs must be machined to produce the desired contour and a smooth, true surface to which the skin may be fastened. If the jigs and operating conditions keep the parts well in line during the gluing of ribs, and if the structure is to be fabric-covered, a simple sanding of the outer surfaces of the ribs may be sufficient.

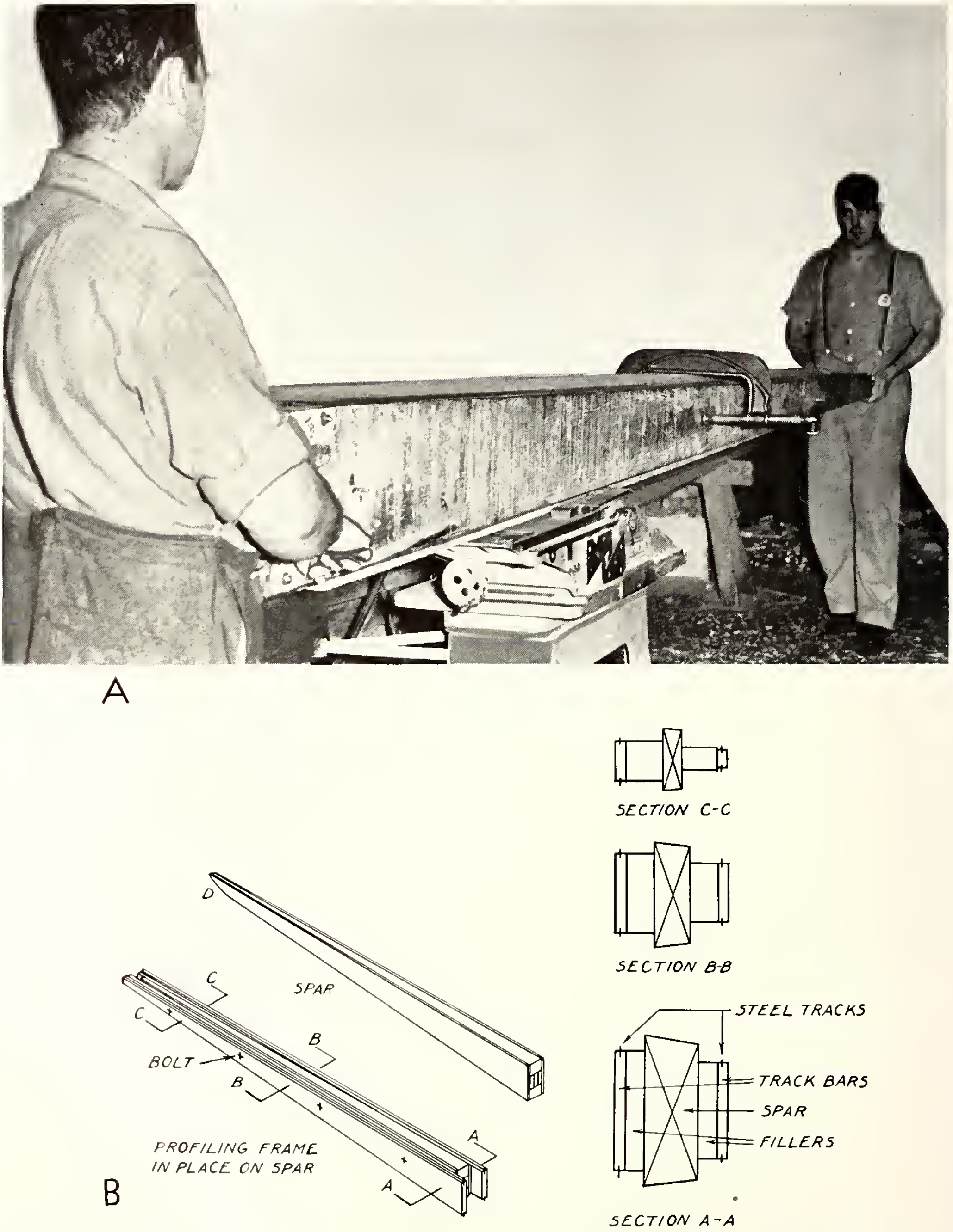

FIGURE 5-81.—Spar profiling: *A*, profiling machine in operation; *B*, details of frame employed for profiling and beveling spars by moving spar past a stationary jointer.

5.654. Contouring with a Router. If, on the other hand, the jig does not hold the cap strips and gusset plates of the ribs accurately to contour, and if the surfaces are later to be covered with plywood, the final contouring of the wing rib must be more carefully done. One method is illustrated in figure 5–82. The rib is clamped against a pattern and, thus guided, is brought to the desired contour. Obviously this operation should be carried out with skill and care to produce a smooth, true surface to which the plywood skin can be glued. After routing, the ribs should move as promptly as possible to the final assembly to minimize surface changes caused by changes in moisture content. If a supply accumulates, the rough ribs should be stored and routed as needed.

FIGURE 5–82.—Routing wing ribs to contour.

5.655. Contouring with a Shaper. Profiling of ribs may also be carried out on a shaper by the use of a jig. The particular arrangement shown in figure 5–83 is for a rib which is attached to the spars at an angle deviating slightly from 90°. The rib is mounted on an inclined or bevel block, the ratio of distance c to distance b being adjusted to give the proper angle. Rib and bevel blocks are, in turn, mounted on a template of uniform thickness which is shaped to impart the exact profile to the rib when the guide block is moved along the shaper collar. In this way suitable bevel cuts may be made on two edges of the rib with a single bevel block. If bevel cuts are to be different at front and rear spars, for example, or if top and bottom bevels are different, as is usually the case because wings taper toward their tips, a second bevel block is used so that the ratios among distances a, b, and c can be varied.

5.656. Shaping Box-section Framing Members. The shaped edges of box sections may present an unsatisfactory gluing surface for attachment of the plywood skin due to changes in moisture content, dulling of the knives by the glue line, and recovery of the fibers after shaping. As a result, the plywood web may protrude sufficiently beyond the surface of the solid flange to reduce the effectiveness of the glue bond between the plywood skin and the flange of the framing member, either in the gluing operation or in subsequent service. Beveling or rounding the edges of the member as shown in figure 5–84, either in a separate operation or by grinding the proper contour in the shaper knives, will eliminate this difficulty.

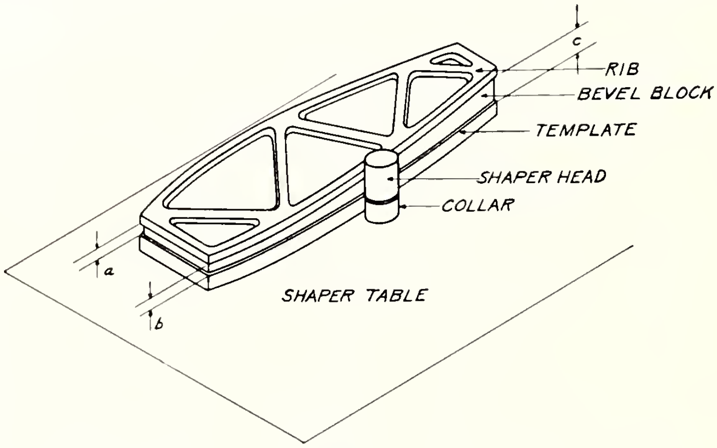

Figure 5–83.—Profiling ribs with beveled edges on shaper by means of bevel blocks.

5.657. Wing-tip Bow Profiler. Large laminated wing-tip bows are sometimes contoured in a jig as illustrated in figure 5–85. The bow is held firmly between side clamps, while the contour is cut by either a power plane or a large portable router which runs on two properly aligned tracks.

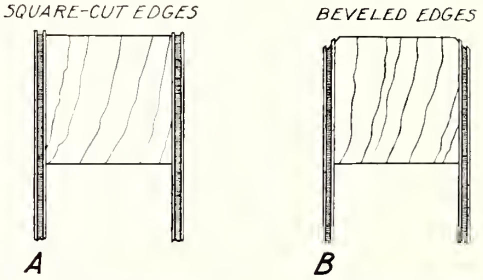

Figure 5–84.—Shaping box-section framing members. (Edge conditions of the plywood are exaggerated.)

5.658. Floating. The surfaces of wing and fuselage frames should be true and smooth. A common method of preparing such surfaces is by "floating." The gross irregularities are removed with hand tools. Final alignment and surfacing are done with sandpaper attached to one side of a board of a length sufficient to extend over several elements of the frame. Considering the wing structure illustrated in figure 5–51, for example, the device for floating the ribs would be a board approximately 1 by 4 inches in cross section and of a length equal to about three-fourths that of the wing. Sandpaper is attached to one side and suitable hand grips to the other.

The device is laid across the ribs and moved more or less parallel to them until their edges are in proper alignment. The same method applies to preparing the surface of the fuselage frame for attaching the plywood cover. If the routing and attaching of the ribs are done with a sufficient degree of exactness, the floating operation may be unnecessary, particularly if the cap strip of each rib is continuous or if only a portion of the surface is to be covered with plywood. If wing ribs or fuselage rings contain cut-outs, special care in the floating operation is required to insure a true surface in the vicinity of the cut-outs.

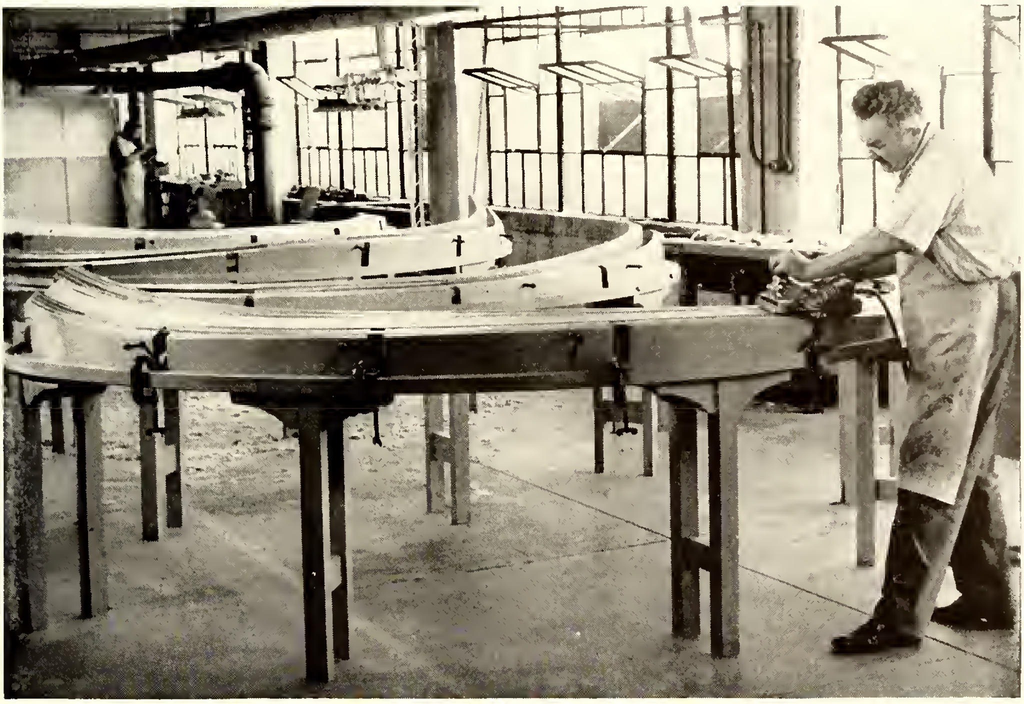

Figure 5-85.—Contouring large laminated wing-tip bows with a power plane.

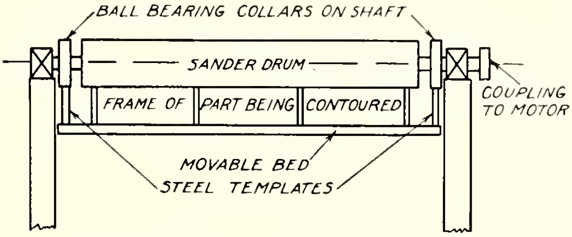

Figure 5-86.—Contour drum sander for aircraft frame work.

5.659. Contour Drum-sander for Framework. A machine method that enables rapid and accurate contouring of assembled air frames, such as the aileron and flat skeleton, is illustrated in figure 5-86. This type of machine will operate on any frame of single curvature, but it is doubtful whether its operation will be sufficiently accurate on very long sections. The frame being contoured is mounted on a solid bed which moves under the sander drum in such a way that the steel templates, which are machined to the exact shape of the finished contour, run against ball-bearing collars on the shaft of the sander drum. The accuracy of the contouring will depend on the rigidity of the sander drum and the proper contouring of the steel templates. The sandpaper should be attached directly to the drum without soft back-up material. Oscillation of the drum is a refinement which might add considerably to the life of the sandpaper.

5.66. Boring. Good boring in aircraft calls for holes that are smoothly cut and true to size. The quality of work will, in general, vary with the kind of wood used, type of bit, and operating conditions (*5–31*). In this operation special attention should be paid to the steadiness of the machines used. As a rule, the harder woods bore better than do the soft ones, which means that extra care must be taken with the latter.

Poor boring often results in some crushing and tearing of the wood immediately around the hole, which exerts some weakening effect on the wood in addition to that resulting from the hole itself. For smooth, clean-cut boring in solid wood the best of many types of bits is probably the machine bit with extension lips. A twist drill, preferably machine-sharpened, has been found to produce a smoother hole in plywood than a machine bit with extension lips. The proper rate of feed depends upon the diameter of drill and the speed, but should be such as to produce only very thin shavings. Manufacturers recommend peripheral speeds of 300 to 400 feet per minute for twist drills of high-speed steel when used in wood. The corresponding speed of rotation (in revolutions per minute) can be computed approximately as 1,350 divided by the diameter of the drill in inches. For carbon steel drills, speeds equal to about one-half the above are recommended.

Holes through a combination of plywood and solid wood, such as in a boy spar, have been bored accurately by using a twist drill slightly smaller than the final size and reaming the hole to final size with a metal cutting reamer.

There are many different types of boring machines, the simplest being the variable speed, single-spindle, hand-feed type common in small woodworking establishments. At the other extreme are highly specialized boring machines designed for quantity production and capable of boring in only a very few seconds a dozen or more holes of the desired depth, spacing, and angle in each side of a piece at one operation. The use of a hand-held electric drill guided by a template around the drill is not recommended.

Frequently it is necessary to bore holes to very close tolerance in alinement and position because holes must coincide with corresponding holes in other parts, such as metal fittings. Such boring, furthermore, must often be done from both sides to avoid the tendency to splinter wood as the bit emerges, or to prevent the bit from wandering too much in deep holes.

Several methods are employed to meet these requirements:

1. Template: All holes are bored, either one at a time or all at once, by boring through a template having glass-hard steel inserts to guide the bit (fig. 5–87). Holes are bored half-depth on one side, the piece is reversed, a template clamped on the other side, and the holes finish-bored. When the template must be removed and refastened, as described, some means of alining must be provided. One method is to bore one or two holes, either separate alining holes or members of a group, all the way through and to use these holes, by means of pins driven into them, to position the template for the second boring. Another is to provide a template frame which consists essentially of identical or reverse-image templates clamped to both sides of the stock. Holes are first bored through the template on one side, then the assemblage is reversed and holes are finish-bored from the other side.

2. Gang drills: Sufficient drills are set in a gang drilling machine to bore a number of holes at once in the desired locations. The material to be bored is set

in position on the bed, usually by means of two pins which fit into alining holes in the stock. Holes are drilled halfway, the stock is turned over and realined, and the holes are finish-bored. This procedure is feasible only when holes are symmetrically grouped about some axis.

One requirement for most boring operations of this kind is that the opposite faces of the stock must be perfectly parallel. When this is not the case, it is necessary to use a parallel-sided boring frame, or to block up the stock during boring so that the two half lengths of the hole are in perfect alinement.

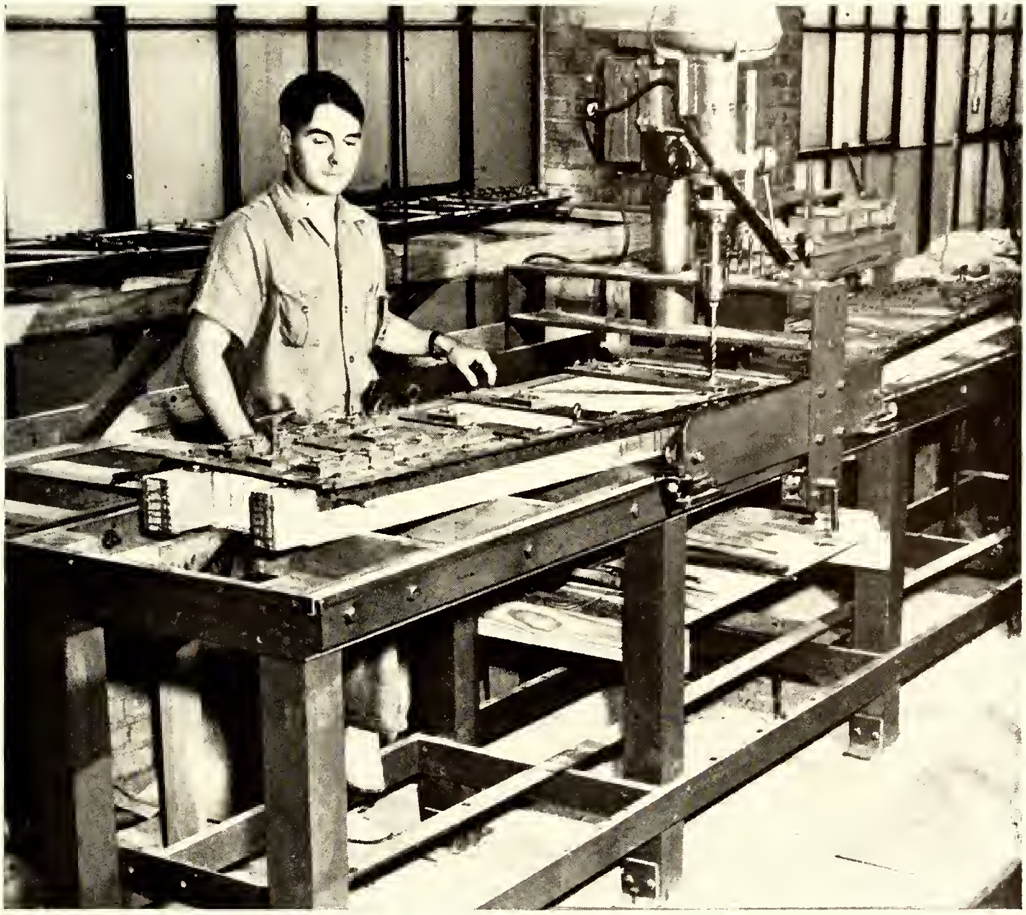

Figure 5-87.—Template for boring spar shear webs.

Holes for bolts or bushings should be bored only after a period of conditioning following the last gluing operation on the material through which they pass. The diameter should be such that the bolt or bushing fits closely but can be inserted with the application of a moderate amount of force. No heavy driving should be necessary.

5.67. Cutting Gussets and Other Plywood Parts of Curved or Irregular Shape. Gussets are of two types: patch and continuous. Both find their greatest use in joining rib webs to cap strips and in making attachments such as those joining ribs to spars. In any event, they are usually irregular in shape and are apt to be small.

Both types of gussets are generally cut by band sawing or routing, but may be cut by steel-rule dies and "clicking machines."

When cutting is done by band saw or router, a number of sheets of plywood are stacked up and cut simultaneously. For band sawing, the top sheet may be marked to pattern and acts as a guide for cutting the entire stack. The shaping of certain curved parts, such as long plywood rib gussets, can be done on a band saw by means of templates and the device illustrated in figure 5–88. The template rides against small follow pins installed in the upper saw guide on either side of the saw. Proper allowance for the distance between the outer side of the pin and the inner side of the saw is made in laying out the template. A narrow saw with considerable set is necessary for cutting to a small radius of curvature. A commercial device of this nature is covered by a patent. For routing, a template is employed to guide the router bit.

Steel-rule dies consist essentially of thin, sharpened steel strips set into the bed of a press, the strips being bent to form patterns yielding pieces of the proper shape from a sheet of stock when the press is closed. When the dies are equipped with spring ejectors, the punchings are rapidly and easily removed.

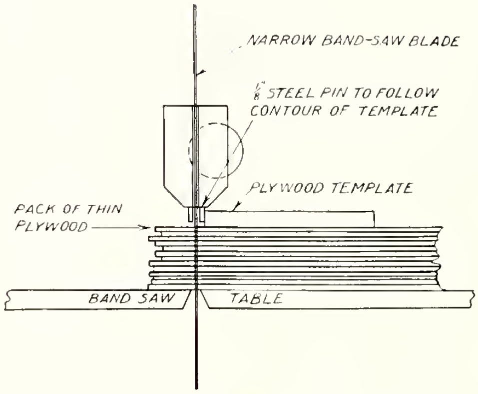

FIGURE 5-88.—Band saw with template guide for shaping long plywood rib gussets.

"Clicking machines," generally used for cutting irregularly shaped leather parts, also employ patterns made of sharpened steel strips. Commonly, the patterns are movable and are merely laid in place on the stock to be cut, each sheet of which is different in size and shape. They can, however, be fixed to the head of the machine to speed up operations when the stock is of uniform length and width, as is generally true of plywood.

Cutting edges of steel-rule dies and clicking-machine patterns may be single-beveled, either inward or outward, or double-beveled, depending upon the type of edge desired on the finished pieces. In any event, one thickness of stock is generally cut at a time, although, if the sheets are very thin, more than one can be handled simultaneously.

Fuselage bulkheads or rings are frequently cut out of solid plywood or utilize plywood webs in combination with other parts. In either instance, the plywood is most easily cut to shape by routing, the number of pieces which can be handled at one time depending upon the thickness of the material and the length of the router bit.

5.68. Formation of Curved Parts. Such curved parts as fuselage rings, door frames, and wing-tip bows may be formed by band sawing, steam bending, or laminating.

5.680. Band Sawing. Curved parts of either single or double curvature can, of course, be formed by band sawing or otherwise shaping them from solid wood. If the curvature is abrupt or passes through a large angle, the piece will be fragile and weak because the grain of the wood will necessarily be at a large angle with the axis of the member. Plywood is somewhat superior to solid or laminated wood for band-sawed. curved parts, but the handicap of cross grain is still present, and parts of high strength cannot be made in this way.

Fuselage rings for planes of one model have been made by band sawing from plywood with reportedly satisfactory results in service. Excellent utilization was reputedly attained by cutting a series of rings of successively decreasing size from the same sheet of plywood and, in addition, using small scraps for other purposes.

Curved pieces or rings band sawed from plywood serve satisfactorily as shear webs in curved members of I or box forms of cross sections. Parts of single curvature band sawed from plywood are less subject to change in shape with change in moisture content than those formed in other ways.

5.681. Steam Bending. Steam bending consists of softening wood by steaming or some other means, after which it is bent against a form of the required curvature. Hardwoods are much better adapted to this process than are softwood species.

5.6810. Moisture Content. Wood at all stages of seasoning, from thoroughly green to well air-dried, has been used in various industries that make steam-bent Parts. Seasoned wood with a moisture content not lower than 12 percent seems to bend as well when steamed as that at higher moisture content, and its use simplifies the seasoning subsequent to bending.

5.6811. Selection of Stock. Preferably, stock is prepared so that the faces that are to become convex or concave are flat sawn. This orientation, besides reputedly adding to success in bending, reduces the tendency of the curved piece to change shape with changes in moisture content. Clear, straight, grain stock is required.

5.6812. Softening Process. The usual conditioning or softening process consists of steaming at atmospheric pressure (steaming at higher pressures does not seem to be advantageous) or soaking in hot water—ordinarily for about an hour per inch of thickness of the stock, although it is probable that a shorter period will suffice in many instances.

5.6813. Tension Straps. In making severely curved pieces, metal tension bands or straps (*5–32*) are used on the side of the piece that is to be convex in order to restrain tension failure and to cause most of the required deformation to take place as compression or upset, the amount of which is greatest at the concave and decreases roward the convex face.

5.6814. Radius of Curvature. When the wood is properly selected and properly manipulated, bends with a radius of as small as 3 or 4 times the thickness of the piece can be formed in such species as the hickories, elms, and ashes. Pieces with double curvature can also be formed.

In aircraft construction, steam bending is likely to be used only for parts of relatively moderate curvature that do not require the use of reinforcing bands. Parts such as cap strips of some wing ribs can be formed by bending to the required shape without preliminary softening treatment. This is applicable only to parts that will be held to the required curvature by their attachment to other members, since bends made in this way are not permanent and tend to straighten out. Some of the other methods of bending should be used when the curvature is such that visible wrinkling or compression failures are formed at the concave face of the bend or tension failure occurs along the convex face.

5.682. Laminating. Curved members of highest strength and stiffness are formed by laminating them from a number of pieces, each of which is thin enough to be bent to the required curvature. with much less distortion than is involved in steam bending of a member of the same size. The members are formed by bending the laminations and gluing them together in one operation (sec. 5.43), laminations being made sufficiently thin that no softening treatment is necessary.

5.6820. Material. The material may be either sawed lumber or veneer, according to the thickness as governed by the radius of curvature. Bending is facilitated and the use of somewhat thicker laminations is possible if the stock is at a fairly high moisture content. On the other hand, the moisture content before gluing should be adjusted wherever possible so that the moisture content when increased by the water added with the glue is not more than 12 percent (sec. 5.20). The amount of moisture added by the glue to thin laminations is likely to be comparatively large (sec. 5.20).

An advantage of laminating is that some of the heavier, harder woods may be used in parts of the cross section where their qualities are desirable and the remainder made of lighter woods.

Although not substantiated by available data, it is generally believed that flat-sawed lumber or rotary-cut veneer can be bent more severely than edge-grained lumber or quarter-sliced veneer. From the standpoint of change of curvature with change of moisture content (sec. 2.240), the use of flat-sawed lumber or rotary-cut veneer is advantageous, since the shrinkage in the direction of the thickness of laminations is thereby lessened.

5.6821. Required Thickness of Laminations. Aside from the question of moisture content and the fact that, as brought out under section 5.6820, the moisture added with the glue increases as the thickness decreases, the choice of thickness of laminations is affected by other considerations. Under section 2.466 it is provided that, in curved flanges of box spars, the radius should not be less than 500 times the thickness of the lamination, and such a limitation should be applied to other parts similarly highly stressed. In laminated parts, such as wing-tip bows, whose principal function is to serve as formers and as connections between other parts, the principal considerations are to minimize the resistance to bending and thus to reduce the forces that must be applied and to avoid breakage and loss in bending laminations.

When a laminated part of a given total thickness is made up of laminations all of which are the same thickness, the force required for bending decreases in almost exact proportion as the number of laminations is increased; for example, the force is approximately one-half as great for four ¼-inch laminations as for two ½-inch laminations.

Complete and systematic data are not available relative to the radii to which lumber and veneer in a dry and unsteamed condition and of various thicknesses can be bent without breakage. In bending nominal 1-inch southern pine or Douglas-fir of construction grades as laminations in arches and other large curved members, it has been found that the minimum radius that can be reached, in material at 10- or 12-percent moisture content without tension failure, is approximately 80 times the actual thickness. On the other hand, current data, some of which are presented in section 5.6830, indicate that for plywood and veneer, the ratio of minimum radius to thickness decreases as the thickness decreases.

In the fabrication of laminated parts on a production basis, it is suggested that at least reasonable factors of safety be applied to these estimated breaking radii in order to reduce the forces required for bending and to avoid breakage or overstressing of laminations. At any rate, the thickness of the lamination should never be so great that tension breaks on the convex face or visible compression buckles or wrinkles on the concave face are formed.

5.6822. End Joints in Laminations. When end joints in laminations are necessary, they should be scarf joints, glued before the laminations are assembled to form the curved part. The scarf joints are, of course, stronger than butt joints;

furthermore, because a square-ended piece cannot be bent all the way to its end, it is difficult to get properly distributed gluing pressure on the faces of laminations in the vicinity of a butt joint.

5.6823. Formation of Complete Rings. Complete rings, such as fuselage rings, may obviously be made by joining laminated curved pieces end to end with glued scarf joints. Laminating complete rings with concentric laminations is complicated by the necessity (unless open-end joints are permissible) of cutting each lamination to an exact length. A method for avoiding this that has been used to some extent consists of spirally wound, instead of concentrically arranged, laminations (sec. 5.430).

5.6824. Double Laminating. "Double laminating" is a procedure adapted to the formation of fuselage door frames, cockpit coamings, reinforcement around curved openings in curved surfaces, and similar doubly curved members.

For example, for a fuselage door frame with rounded corners there would first be formed a continuous laminated ring of approximately the shape seen in a side view of the fuselage. This ring would then be sliced into a number of thin rings. These would next be assembled with glue and bent to the curvature required to fit the cross section of the fuselage.

Obviously, if the curvature in the section direction is not large it may be more economical to form it by band-sawing or some equivalent operation.

5.683. Bending of Plywood. Much of the plywood used in aircraft is manufactured flat and bent to the required form. The amount of curvature that can be introduced into a flat piece of plywood depends on numerous variables, a few of which are moisture content, direction of grain, thickness and number of plies, species and quality of veneer, and the technique applied in producing the bend.

The use to which the bent plywood part will be put should govern its thickness, number of plies, and direction of grain. Once these factors are established, the method of producing the bend can usually be determined.

Bent plywood parts are more likely to be changed in shape by subsequent moisture changes than are molded plywood parts which have been glued up in a curved shape. This usually limits bent plywood pieces to those which are supported at frequent intervals by a rigid framework.

5.6830. Radius of Curvature. The minimum radius beyond which it is impossible to bend a piece of plywood or veneer without fracture decreases when any of the following conditions prevail:

1. Thickness is decreased.
2. Face plies are laid more nearly parallel to the axis of bend.
3. Moisture content of the plywood is raised.
4. Temperature of bending form is raised.
5. Quality of veneer is increased (particularly by minimizing cross grain).
6. Technique of bending is improved.

In most applications of plywood in aircraft it is not practical to approach very closely to this breaking radius, as considerable allowance must be made for variations in veneer quality and the method of holding the bent plywood in place while it is fastened to the supporting structure. Furthermore, bending to the extreme is inadvisable because of the effect on subsequent performance of the part. If, however, the breaking radius is known for different face-grain angles and conditions of plywood, approximate factors of safety can be applied which will enable the builder of a bent plywood aircraft part to specify more closely the proper treatment of the plywood.

Limited data are available on the relation between breaking radius and thickness of plywood and veneer under several conditions. Some of these have been derived from actual factory practice and some from tests at the Forest Products Laboratory. An approximate relation between thickness and breaking radius of plywood is presented in figures 5–89 and 5–90. It may be noted by reference to the plotted relations that no constant ratio of radius to thickness can be set for all thicknesses.

The graphs shown in figures 5–89 and 5–90 are based on tests of plywood between 0.035 and 0.375 inch in thickness of aircraft construction and quality (AN–NN–P–511b), but it is believed that the curve for the 90° angle and 10-percent moisture content may also be applied in estimating the breaking radii of veneer and air-dry lumber between 0.01 and 1 inch in thickness, and that the curve for 90°, hot-soaked material may also be applied to veneer that has been soaked in hot water prior to bending on a heated form, as described below.

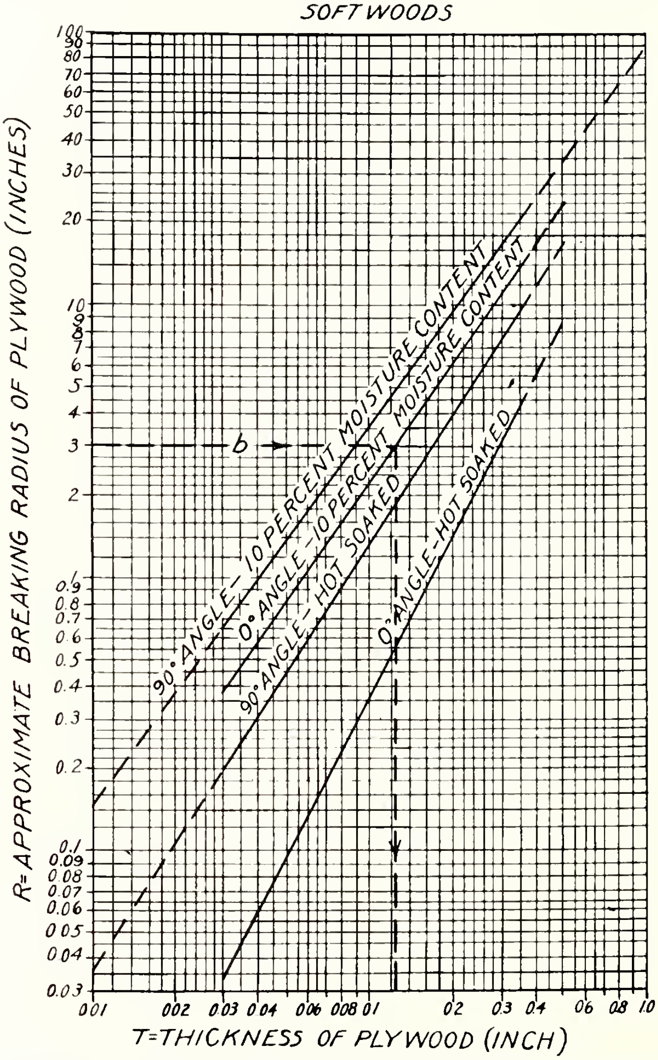

FIGURE 5–89.—Approximate relation between thickness and breaking radius in the bending of softwood plywood. Softwoods tested were Douglas-fir, Sitka spruce, and western white pine. (For explanation of this graph, see section 5.6830.)

The angle referred to on each graph is the angle between the grain direction of the face plies and the axis of the bend. Most of the tests were made at the 0° or 90° angle, but a few tests on wider strips of plywood at 45° indicated that there was little or no difference between results at the 0° and 45° conditions.

"Hot soaked" means that material is thoroughly soaked in hot or boiling water until the plywood sinks, after which it is bent over a mandrel heated to approximately 300° F.; "10 percent moisture content" means plywood of this moisture content bent over a cold mandrel.

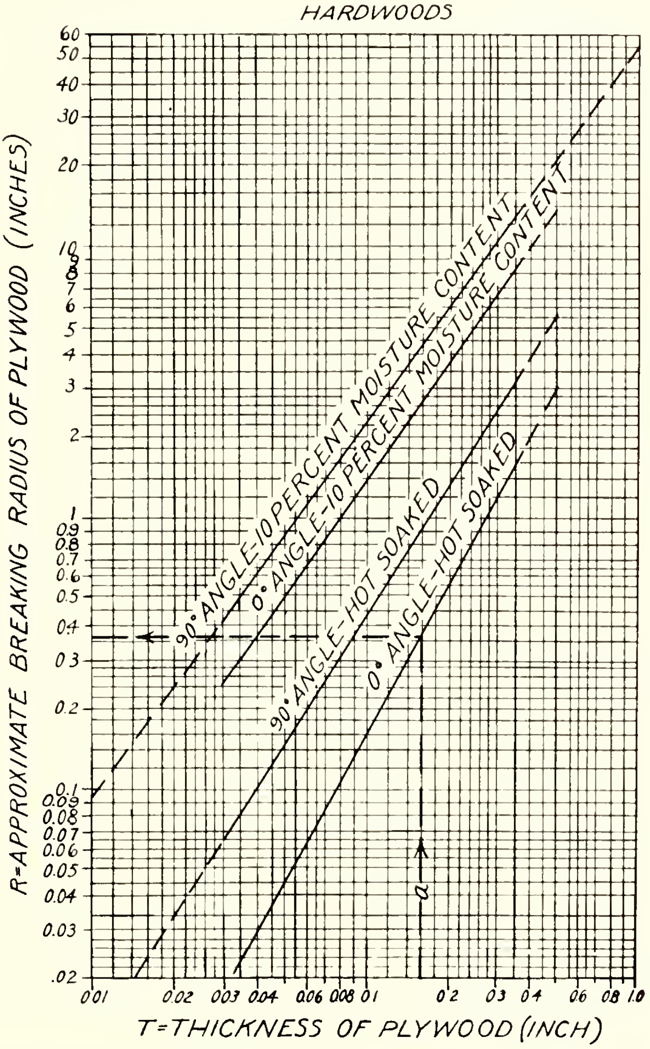

FIGURE 5-90.—Approximate relation between thickness and breaking radius in the bending of hardwood plywood. Hardwoods tested were yellow birch, hard maple, sweetgum, yellowpoplar, black walnut, and mahogany. (For explanation of this graph, see section 5.6830.)

The curves represent average breaking radii of plywood strips 1 inch wide, bent slowly over mandrels with no support on the tension side. Broken lines "a" and "b" on the graphs refer to the examples given in the text.

The tests were made by slowly bending strips of aircraft plywood around a series of mandrels of decreasing size until fracture occurred. In most cases, each sample was bent through an angle of at least 90°. Separate curves are shown for plywood bent at 10 percent moisture content around a cold mandrel and for hot-soaked plywood around a heated mandrel. For each condition, the breaking radius is shown for plywood bent with the face grain direction at 0° and 90° to the axis of the bend. It is assumed that the same values would be obtained if wider plywood sheets equal in quality to the narrow strips were used. All the plies in each strip of plywood were of the same species. It is suggested that plywood containing a combination of species be considered to have the same bending radii as plywood made entirely of the face-ply species.

Soaking in water at room temperature can be expected to produce a degree of flexibility or a reduction in breaking radius intermediate between that of dry and that of hot, water-soaked wood. Bending plywood at 10 percent moisture content over a hot mandrel is also an intermediate treatment, and a breaking radius between that for dry and hot, water-soaked wood may be anticipated. This treatment is probably more effective on thin plywood than on thick material.

5.6831. Factor of Safety. In any instance, it is desirable to multiply the breaking radius obtained from figures 5–89 and 5–90 by a factor of safety in order (1) to get a working radius that will provide against overstressing in bending, (2) to allow for inapplicability of figures 5–89 and 5–90 to the case in hand, (3) to avoid face checking of plywood, (4) to reduce the forces required to form the bend and hold the bent part in position, and (5) to allow for the fact that, during placement in female molds, veneers must often be bent to a radius shorter than that to which they are held after they are in final position.

A factor of safety against breakage of at least 3 applied to the radius is suggested for all bending of thin, exposed, finished plywood on aircraft where smoothness of the convex finished surface is important. As an illustration, figure 5–90 indicates a breaking radius of about 2 inches for 0.1-inch Douglas-fir plywood at 10-percent moisture content bent at a 0° angle. A minimum working radius of 3 times 2, or about 6 inches, is suggested. On unexposed parts, this factor of safety may be reduced if fairly prominent face checks are not objectionable.

Interior parts, such as plywood seats and angles, are often steam bent to the radii indicated by figure 5–90 and even sometimes to a slightly smaller radius when a well-developed technique such as the use of heated male and female dies is employed in the bending.

5.6832. Examples Showing Use of Figures 5–89 and 5–90. To what radius can 0.160-inch birch plywood of aircraft quality, after soaking in hot water, be bent on a hot mandrel with the face grain at 45° to the axis, allowing a factor of safety of 3 against breakage? Starting at "t=0.160 inch" on the graph for hardwoods, R is found (line "a" on graph) to be 0.37 inch, which, multiplied by 3, gives 1.11 inches as the safe bending radius.

What thickness of Douglas-fir plywood can be safely bent dry and unheated, with the face grain parallel with the axis of the bend, to a 9-inch radius? Using a factor of safety of 3, the breaking radius is read on the figure as 3 (9÷3=3). From this radius on the softwood curve, the thickness is found (line "b" on graph) to be about 0.125 inch.

5.6833. Compound Curvature. No simple criterion is available for predetermining whether a surface of compound curvature can be covered with flat plywood (*5–33*). Soaking the plywood and the use of heat during application are aids to manipulation. Some compound curvature can be imparted to flat plywood by die molding. Figure 5–91 illustrates one method of bending a flat sheet of plywood to double curvature. The plywood is first soaked in hot water and then dried between heated male and female forms that have been attached to a hydraulic

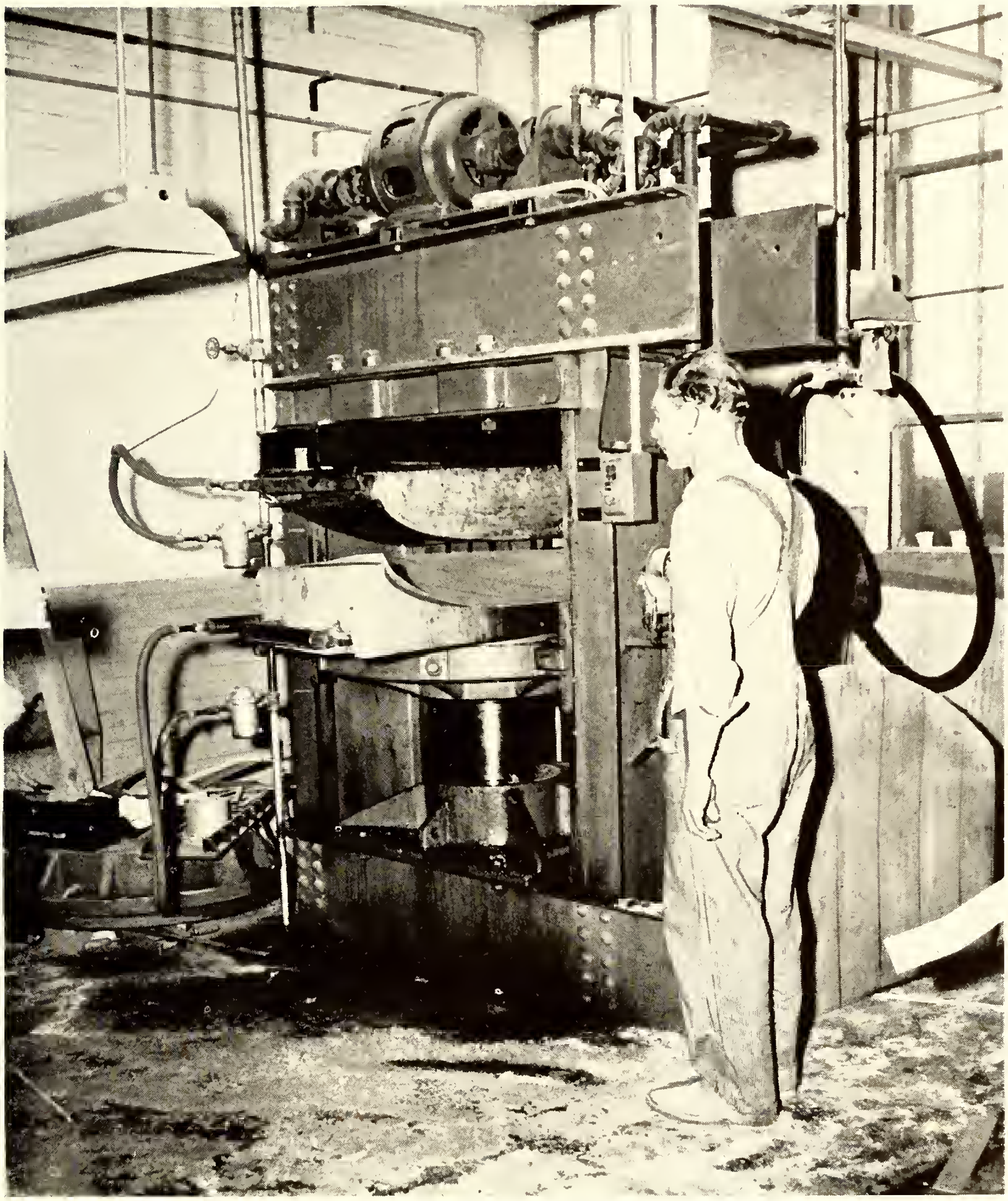

FIGURE 5-91.—Bending flat plywood to desired shape between heated plates.

press. In case the use of flat plywood on surfaces of compound curvature is contemplated, experiments to determine the possibility and the best procedure are recommended. The following discussion relates to the application of plywood to surfaces of single curvature.

5.6834. Plywood Bent Without Softening. Thin plywood wing and fuselage skins are often applied without softening to the supporting structure with the face grain parallel (0° angle) or at a 45° angle to the axis of curvature. Either of these directions permits a smaller radius of curvature, and the plywood can be bent with less force than when the face grain is circumferential or at right angles to the axis (90° angle).

When bending at a 0° angle, small face checks will appear long before the breaking radius is reached. The radius at which these face checks become objectionable will vary with the species, thickness of face ply, and quality of surface required.

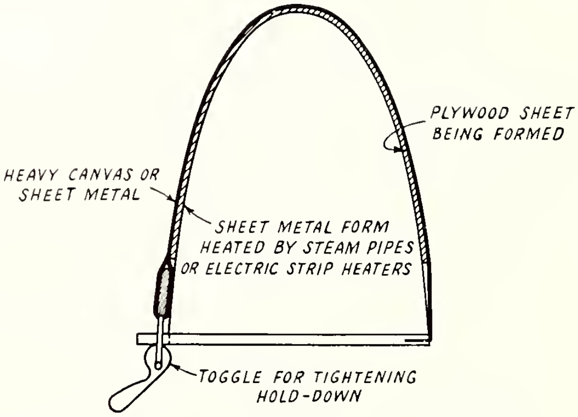

FIGURE 5–92.—Steam-bending form for plywood leading edge.

5.6835. Plywood Bent After Soaking or Steaming. When only a portion of a flat sheet of plywood is to be bent to a severe radius of curvature, it is common practice to soak only this portion by sponging it until thoroughly wetted with hot or cold water before bending. A strip of wet cloth laid on the area to be bent will accomplish the same result as repeated sponging. If the entire piece is bent to a small radius, or if it is desired to reduce the force necessary to hold a piece of varying radius of curvature in place while attaching it to the supporting frame, the whole sheet should be soaked or steamed. In either instance, the sheet can be bent over a form, preferably heated to facilitate the bending and to reduce the drying time, similar to that shown in figure 5–92.

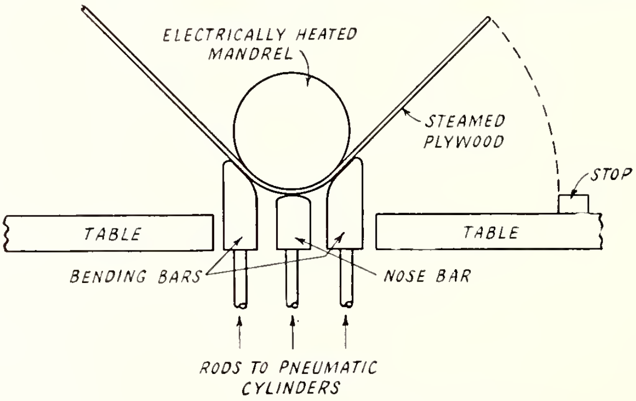

FIGURE 5–93.—Cross section of steam-bending machine.

Steam-bending machines, the elements of one type of which are shown in figure 5–93, are often used. These machines (fig. 5–94) can be automatically controlled by cycle timers, so that it is only necessary to insert flat sheets of plywood that

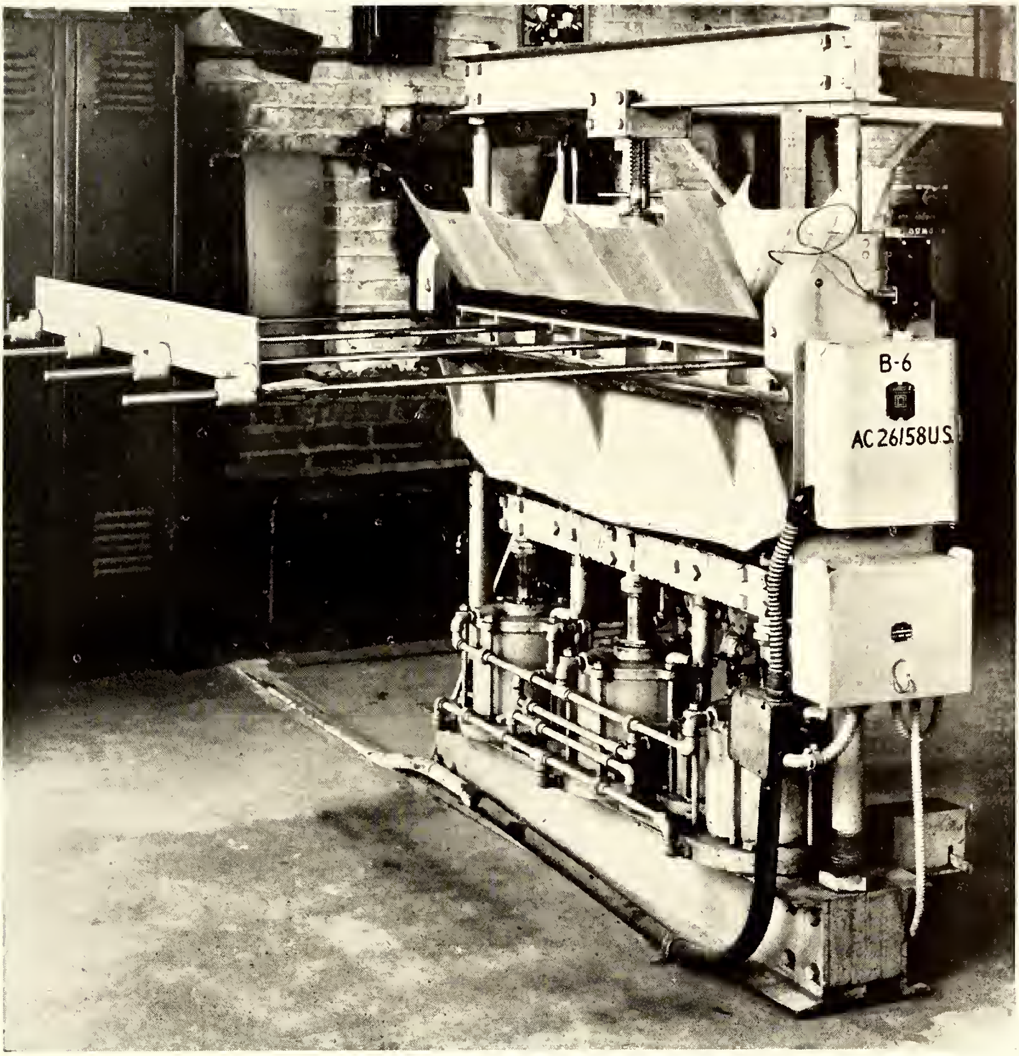

FIGURE 5–94.—Commercial machine used for bending plywood.

have been steamed or soaked and remove the bent pieces after an interval of 2 to 5 minutes. For severe curvatures, the plywood is soaked for 1 to 2 hours at 150° to 200° F., and the mandrel is usually maintained at a temperature of 300° F. or higher.

Following are examples of bends that have been produced commercially on a machine of this type:

(1) Five-ply, all plies one-twenty-eighth inch birch. (Total thickness 0.178 inch.) Face grain 90° (circumferential) to mandrel. Bent to 1-inch radius through an angle of 90°.

(2) Three-ply, faces one-twentieth inch birch, core one-sixteenth inch poplar. (Total thickness 0.162 inch.) Face grain 90° (circumferential) to mandrel. Bent to 1-inch radius through an angle of 90°.

Under some bending conditions, plywood of 5 plies is less susceptible to fracture than 3-ply material of similar thickness probably because each ply is somewhat thinner. The thickness of veneer is important, particularly that of the face veneer.

In preforming plywood by any wetting and drying technique, there is a certain amount of spring-back, for which allowance must be made if accuracy is desired. Spring-back depends on thickness, moisture content, temperature, bending time, ratio of radius to thickness, and other factors. As an allowance for spring-back, some operators bend soaked plywood on heated forms having a radius of curvature about 20 percent less than the desired radius of the bend.

5.69. Woodworking References.

(5–31) Davis, E. M.
1942. MACHINING AND RELATED CHARACTERISTICS OF SOUTHERN HARDWOODS. U. S. Dept. Agric. Tech. Bull. No. 824, 42 pp.

(5–32) Wilson, T. R. C.
1941. WOOD BENDING: WITH APPENDIX ON APPARATUS FOR BENDING BOAT RIBS. Forest Products Laboratory Mimeo. R966.

(5–33) Norris, Charles B.
1939. INTERPRETING THE DEFORMATIONS AND STRESSES MET IN MOLDING PANELS OF COMPOUND CURVATURE. Hardwood Record, May 1939, pp. 7–16, illus.

5.7. FINISHING WOOD IN AIRCRAFT.[9]

5.70. General. Aircraft specifications for the Army or Navy usually require that all exposed surfaces of wood, either interior or exterior, be finished with a protective coating. Exterior surfaces are those that are exposed to the weather and to view from outside the craft. Interior surfaces may be further subdivided into those seen by occupants of the craft, such as the interiors of fuselage compartments, and those ordinarily remaining entirely unseen, such as interiors of wings, hollow spars, stabilizers, ailerons, flaps, rudder, and closed portions of fuselage and nacelles. Areas of contact between wood and metal may also be considered interior surfaces requiring finish.

The plans and specifications of the prime contractor indicate in detail where finish is to be applied, what finish is to be used, the number of coats, how it is to be applied, and other points about the finishing procedure. Alternates may be permitted subject to the approval of the prime contractor, who is in turn subject to the specifications or the specific approval of the military authorities. Specifications for finishing materials and finishing systems should, of course, conform to current Army, Navy, or Federal specifications wherever such Government specifications are applicable. The specification of finishing materials by trade brand or manufacturer's code number is meaningless unless the products have been competently tested for conformity to Government or other authoritative specifications.

5.71. Requirements of Finishes. The surface of wood is vascular and moderately absorptive of liquids. Wood surfaces, therefore, must be rendered nonabsorptive by applying sealer or primer, which penetrates only far enough to close the openings in the surface, before a uniform coating of finish can be spread over the surface (*5–54*). Hardwoods with pores as large as those in birch require wood filler applied by wiping across the grain of the wood to plug the large pores. If a finish with mirror-like smoothness is required, wood of any kind usually must be coated with sanding surfacer, part of which is sanded away after it has dried, to yield a perfectly smooth surface for the application of enamel or lacquer enamel.

To be durable, wood finishes must remain somewhat plastic throughout their useful life so that they can accommodate themselves to the changes in shape and dimensions of the surface. The required degree of plasticity usually runs counter to the desire for speed in drying and hardness of coating; plasticity is provided by drying oils or soft resins, whereas fast drying and hardness come from hard resins or cellulose esters.

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[9] A more detailed discussion of the subject has been prepared by the Forest Products Laboratory for restricted circulation in Mimeograph No. 1396, Finishing Wood in Aircraft (*5–57*).

Aircraft finishes should be as fast in application as is consistent with their primary objectives. The number of finishing operations should be held to a minimum and the over-all time required for drying should be as short as possible either by reason of the limited number of coats applied or because of fast drying of each coat. Although wood finishes cannot be baked to speed drying, the process can be speeded by forced drying at temperatures up to 150° F. with sufficient humidification to avoid undue loss of moisture from the wood.

Finishing systems when dry should add as little weight to aircraft as is consistent with the attainment of their primary objectives.

The primary objective of interior finishes is to afford protection of the wood against serious change in moisture content when exposed for a limited time to damp air or to water that gains access to closed spaces by condensation or by penetration of rain, mist, or fog through joints, vent holes, bullet holes, or imperfections in the covering. Coatings on contact areas between wood and metal protect the metal against corrosion from moisture in the wood.

Interior finishes must retain their protectiveness for the life of the aircraft and throughout the great range in temperature to which the craft may be subjected in service. They need not be capable of withstanding exposure to the weather, including sunshine, for any such length of time.

The primary objectives of exterior finishes are protection of the wood against weathering, sufficient smoothness of surface to minimize skin resistance during flight, suitable appearance, and enough durability to retain these properties for several years of full exposure to the weather at all altitudes of flight even in the most severe climates. The finish should be easy to keep clean and should wear in such a way that it can be renewed when necessary with minimum increase in the weight of coating.

Appearance is important from a military, not a civilian point of view. Combat and task craft require a dull surface, free from gloss, of a color chosen for camouflage. Training planes may have semigloss or gloss finishes of bright color when so specified by the procuring agency. The appearance of interior finishes is unimportant except for those visible to occupants of the craft, for which a dull surface and subdued color are desirable.

Finishes do not preserve wood against decay and do not prevent blue stain in sapwood. Decay and blue stain develop only when wood is exposed to dampness for some time, a condition under which protective coatings are low in protectiveness. Even if toxic substances are added to sealers and finishes they do not prevent fungus attack because they do not penetrate far enough into the wood. Water repellents containing toxics are moderately effective against decay and blue stain when applied in such manner that deep penetration and good absorption are obtained but the water repellents are poor sealers and are not high in protectiveness.

5.72. Protective Power of Wood Finishes. When unprotected wood is exposed alternately to dampness and dryness, such as to rain and sunshine, the portions of the wood near the surface change in moisture content more rapidly and more widely than do the interior portions. Such unequal distribution of moisture within pieces of wood sets up internal stresses that are responsible for such processes of weathering as grain-raising, cupping, warping, checking, and softening and disintegration of the surface. Protective finishes guard against weathering by retarding the rate at which moisture passes through them, either into or out of the wood surface, to such an extent that a reasonably uniform distribution of the moisture within the pieces of wood is always maintained and internal stresses are thereby avoided.

A finish entirely impermeable to moisture has not yet been found (*5–55, 5–60*). Moreover, no finish alters the fiber-saturation point or the swelling coefficient of wood. Figure 5–95 shows the effects of a series of finishes ranging from very low to high protectiveness on the moisture content of matched specimens of 3/32-inch, 3-ply, aircraft plywood (conforming to Army-Navy Aeronautical Specification

AN-NN-P-511b), uncoated and coated on all surfaces with the various finishes. The specimens were brought to constant weight in 65 percent relative humidity at 80° F., then placed in 97 percent relative humidity at 80° F. for weighings at intervals during 42 days, and finally returned to 65 percent relative humidity for weighings during another 42 days. When exposed to 97 percent relative humidity, uncoated specimens and specimens with finishes of low protectiveness reached equilibrium close to the fiber-saturation point within little more than 10 days, whereas specimens with highly protective coatings required 90 days or more to reach equilibrium. Very similar curves are obtained if swelling is measured instead of moisture content. On return to 65 percent humidity, those finishes that retarded absorption to the greatest extent likewise retarded drying most effectively. After equal periods of absorption and drying (42 days) all specimens retained more than their initial moisture content and the extra moisture retained increased with the protectiveness of the finish.

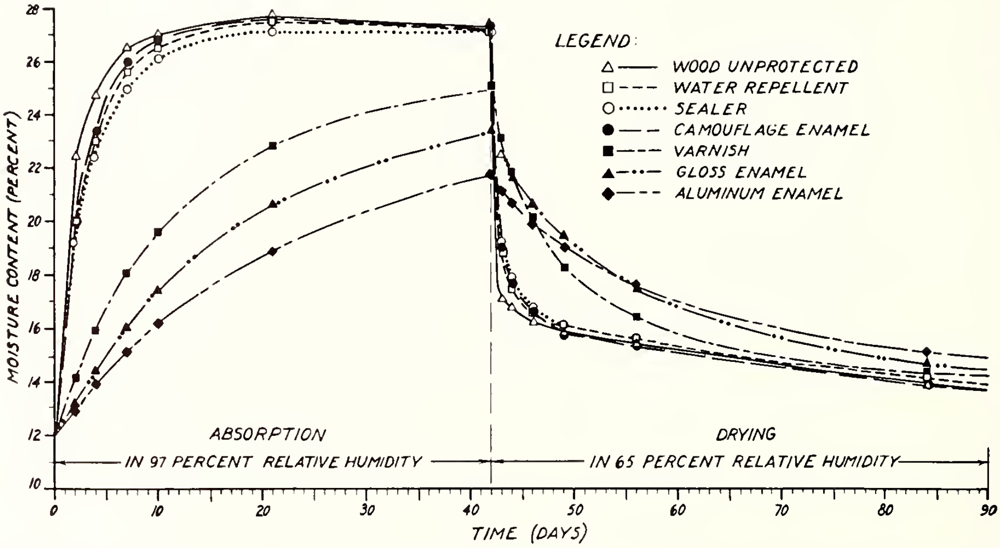

FIGURE 5-95.—Average absorption of moisture and drying of 3-ply, 3/32-inch aircraft plywood when protected with six basically different finishes. The water-repellent finish consisted of 1 dip for 3 minutes and weighed 0.002 lb. per sq. ft.; the sealer was made of phenolic resin at 12½ gal. length in tung oil and 30 percent nonvolatile with 2 dips for 5 seconds each and weighed 0.007 lb per sq. ft.; the camouflage enamel was placed over the above sealer and consisted of 1 dip in each and weighed 0.045 lb. per sq. ft.; the varnish was made of phenolic resin at 33 gal. length in oil and 60 percent nonvolatile with 3 dips for 5 seconds each and weighed 0.032 lb. per sq. ft.; the gloss enamel was made with chrome yellow in phenolic resin varnish with 2 dipped coats over 1 dip in the above sealer and weighed 0.047 lb. per sq. ft.; the aluminum enamel consisted of 3 dipped coats of aluminum pigment in the above varnish and weighed 0.038 lb. per sq. ft.

The protective power of finishes is conveniently expressed in terms of moisture-excluding effectiveness, represented by the symbol *E*, for an arbitrarily chosen time of exposure to dampness under standardized conditions. Using the data of figure 5-95, 7 days is a suitable time of exposure. In 7 days the specimens coated with aluminum finish gained 3.1 percent whereas the unfinished but otherwise similar specimens gained 14.5 percent moisture. The finish therefore excluded 14.5−3.1=11.4 percent moisture, which is 79 percent of the absorption by the unfinished specimens. The moisture-excluding effectiveness of the aluminum finish was therefore 79 percent.

The moisture-excluding effectiveness has relative significance for comparing finishes when tested under standardized conditions, but the absolute values of *E* vary with the test conditions. For example, using the data of figure 5-95, *E* for the aluminum finish was 90, 85, 79, 56, and 37 after exposure for 2, 4, 7, 21, and 42 days respectively. In general, effectiveness decreases as the time of exposure increases, eventually becoming zero. For the aluminum paint in figure 5–95 on different kinds of 3/32-inch plywood after exposure for 7 days, *E* was 75 on yellow poplar, 77 on Douglas-fir, 77 on mahogany-on-yellowpoplar, 79 on spruce, and 83 percent on birch. On sapwood *E* is usually higher than on heartwood of the same species. On spruce specimens of differing dimensions, *E* after 7 days' exposure for the aluminum finish was 27 percent on edge-grain veneer 1/32-inch thick, 43 percent on flat-grain veneer of the same thickness, 79 percent on the 3/32-inch plywood reported in figure 5–95, 91 percent on solid spruce 5/8 by 4 by 8 inches in size with the grain parallel to the 8-inch dimension, 93 percent on solid spruce 1½ by 1½ by 11 inches in size with the grain parallel to the 11-inch dimension, and 96 percent on solid spruce 5/8 by 4 by 8 inches in size with the grain parallel to the 5/8-inch dimension (4 by 8 inch surfaces end grain wood).

Army-Navy Aeronautical Specification AN–S–17 for wood sealer prescribes a test for "water permeability" in which 3/32- by 1- by 3-inch pieces of birch plywood finished with two coats of the sealer are immersed in water for 6 hours and their increase in weight determined. Acceptable sealer must not permit more than an 0.35-gram increase. An unfinished specimen absorbs about 1 gram of water, hence the minimum admissible moisture-excluding effectiveness is 65 percent. When the sealer presented in figure 5–95 with an *E* after 7 days of 10 percent, is tested by the method of AN–S–17, about 0.14 gram of water is admitted, corresponding to an *E* of 86 percent. Finishes afford much greater protection against brief exposure to water than they do against longer exposure to damp air. The difference is due partly to the shorter time of exposure and largely to the fact that unprotected wood takes up free water in addition to fiber moisture, whereas well-protected wood absorbs only fiber moisture.

The six finishes presented in figure 5–95 represent six basically different types of finish. The representative chosen for each type stands near the top in moisture-excluding effectiveness among finishes of its type.

1. Deeply penetrating finishes, such as water-repellant preservatives, afford relatively low moisture-excluding effectiveness. These products are usually applied by dipping once for not less than 3 minutes and their primary purpose is to carry toxicants into the wood as deeply as can be accomplished by brief, nonpressure treatment. Representative specifications for water-repellent preservatives are Army Ordnance HOMB ES No. 680a Class 638 Type 2 and Navy Bureau of Ships 52W5 (INT).

2. Slightly penetrating finishes that form little or no coating over the surface of the wood, such as sealers, are even lower in moisture-excluding effectiveness than the better water-repellent preservatives when only one application is made, but a second application often results in somewhat higher effectiveness than is obtained with repellents. The sealers are designed primarily to render the surface of wood nonabsorptive for the liquids in coating materials applied subsequently, but two or more applications of sealer are used also as a moderately protective finish for surfaces not exposed to the weather. Representative specifications for sealer are Army-Navy Aeronautical AN–S–17 and Army Ordnance HOMB ES No. 680a Class 638 Type 1.

3. Coatings of a porous nature, such as the lusterless camouflage enamels and camouflage lacquers, do not provide much moisture-excluding effectiveness. The data of figure 5–95 indicate that a coat of camouflage enamel weighing approximately 0.04 pound per square foot offers less resistance to moisture movement than an application of phenolic-resin sealer weighing less than one-tenth as much. The sanding surfacer used in some exterior finishing systems likewise forms porous coatings of low moisture-excluding effectiveness.

4. Coatings of a nonporous nature, such as spar varnish, when so applied as to form a film of appreciable thickness (0.001 to 0.003 inch) over the surface of wood, achieve reasonably high moisture-excluding effectiveness.

5. Pigmented coatings of a nonporous nature, such as semigloss or gloss enamel, have materially higher moisture-excluding effectiveness than otherwise similar coatings without pigments.

6. Aluminized coatings, which are pigmented with aluminum in the form of thin flakes, are capable of attaining very high moisture-excluding effectiveness even in thin coatings of light weight. For full effectiveness, however, at least one aluminized coat should be a priming coat or an undercoat, that is, it should be sandwiched between the wood and succeeding coats or between coats. When the final coat only is aluminized the moisture-excluding effectiveness sometimes is no greater than that obtainable with the clear vehicle without the aluminum.

The data of figure 5–95 show that high moisture-excluding effectiveness is obtainable only from continuous, nonporous, moisture-resistant coatings of appreciable thickness over the surface of wood. Penetrating finishes afford relatively little protection although perhaps enough for some purposes. It is also evident that finishes retard drying of wood in the same order that they retard absorption. If wood is exposed to cycles of alternate dampness and dryness in which the dry periods are shorter than the damp periods, highly protective coatings may hold it at higher moisture contents than it would have if left uncoated.

Figure 5–96 is indicative of changes in moisture content of the woodwork within the wings of aircraft that may be expected when planes are parked in the open in a climate like that of Madison, Wis., and the vent holes are allowed to become clogged with dirt or paint or are not so located as to drain promptly after rain water gains entrance during storms. The experiments were made in "dummy wings" (*5–58*) that had previously been used during the summer to study the temperatures attained in hot, sunny weather (sec. 5.74). Some of the glued joints between plywood skins and framework deteriorated during the summer and fall to such an extent that, by winter, water from rain or melting snow gained access to the interior of the dummy wings. Although most of the water admitted drained promptly through vent holes, enough was retained to humidify the air for some time after such entrance.

All test specimens for moisture determinations were at 6.5 percent moisture content on November 14, 1942, when they were placed within the dummy wings. Specimens were of two sizes, $\frac{1}{32}$-inch spruce veneer and $\frac{3}{8}$- by $\frac{5}{16}$-inch spruce sticks representative of the braces and caps of aircraft ribs of truss construction. By early January 1943 the unfinished veneer reached 21 percent moisture content and the unfinished brace 19 percent, after which they gradually dried out again to roughly 12 percent by the end of April except that at four times, once each in February and March and twice in April, there were sudden, overnight upward surges in moisture content. Each surge immediately followed heavy snowfall or rain. Protection of the veneer with two coats of sealer did not measurably alter the January maximum of 21 percent moisture content, which was approached gradually, but it did cut the sudden upward surges following storms nearly in half. Even the higher degree of protection afforded by aluminized sealer failed to keep the veneer from exceeding 19 percent moisture content in early January. Protective finishes were somewhat more effective on the larger pieces of wood representative of braces, but even the aluminized sealer permitted a range in moisture content from less than 6 percent in August (*5–57*) to nearly 16 percent in January. The data illustrate the fact that protective finishes are not very effective in minimizing changes in moisture content that progress slowly over a considerable period of time although they may be highly effective against rapid fluctuations, such as the entrance of water during storms. Even against rapid fluctuations, however, two coats of aircraft sealer make a finish rather low in protection.

Experiments in wings from Anson bombers at Madison in the fall and winter of 1943 and January of 1944 revealed a maximum moisture content of unfinished $\frac{1}{48}$-inch veneers of yellow birch that did not exceed 17 percent except in one place near a leak in the top skin where the moisture content reached 22 percent. Unfinished specimens of spruce $1\frac{1}{2}$ by $1\frac{1}{2}$ by 11 inches in size attained a maximum of 14.5 percent moisture content except near the leaky top skin, where a maximum of 21 percent was attained. Each Anson wing contained 185 vent holes in the bottom skin so placed that water entering the wing drained out as promptly as possible.

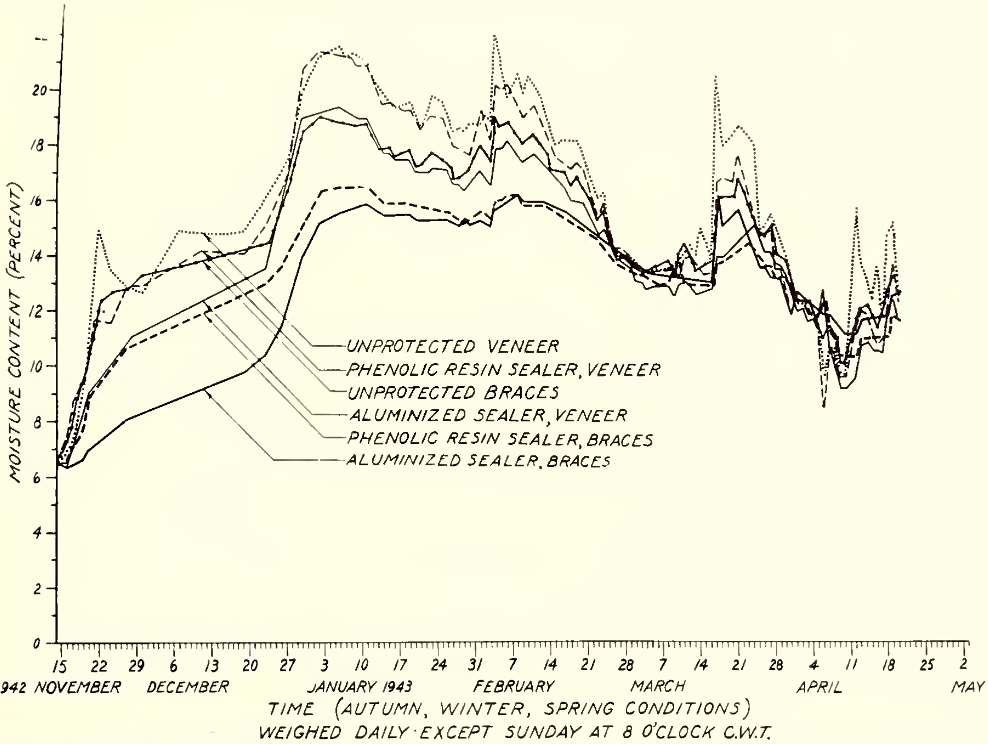

FIGURE 5-96.—Change in moisture content of unfinished and finished wood placed within dummy aircraft wings at Madison, Wis. The wood consisted of spruce veneer $\frac{1}{32}$-inch thick and $\frac{3}{8}$- by $\frac{5}{16}$-inch spruce braces; for each wood size there were one unfinished specimen, one specimen finished with two coats of clear sealer, and one specimen finished with two coats of aluminized sealer.

The studies made in the dummy wings and Anson wings indicate that keeping the top skins of aircraft wings tight against the weather and the bottom skins adequately vented does more toward keeping the moisture content within safe limits than can be accomplished with protective finishes of the kinds now used for aircraft interiors.

5.73. Effect of Finish on Smoothness of Surface. For best aerodynamic performance, exterior surfaces should be as smooth as possible (*5–59*). With suitable finishing systems, wood may be given a surface of mirror-like smoothness. To that end the large pores of such hardwoods as birch and mahogany must be filled and, to level the surface irregularities of all woods, it is necessary to apply sanding surfacer and to sand it smooth before applying the finishing enamel or lacquer. The sanding surfacer, which is a coating very rich in pigment and therefore relatively heavy, makes up approximately half of the total thickness of coating (fig.

5-97). For that reason, finishes of maximum smoothness are relatively heavy, usually approximately 0.05 pound per square foot or even more. They are also laborious in application, inclined to crack and chip badly when they wear out, and are little if any better in protective power and durability than an otherwise similar finish from which the sanding surfacer has been omitted and the weight reduced to 0.025 to 0.03 pound per square foot. The tendency at present, therefore, is to leave out sanding surfacers and to accept the somewhat rougher finish, often still revealing the grain pattern of the wood, that results.

Finishes of mirror-like smoothness are necessarily glossy, reflecting light specularly. On task and combat craft, where camouflage is required, some sacrifice of smoothness must be made to obtain lusterless finishes that reflect light diffusely.

5.74. Absorption of Heat by Finishes. Stagnant or nearly stagnant air spaces enclosed by thin skins, such as occur in the wings of aircraft, may become heated when exposed directly to sunshine. The rise in temperature is greatest on cloudless days with little or no wind when the sun is closest to the zenith and the plane stands so that the surface is most nearly normal to the direction of the sun's rays. If all of these factors are constant, the rise in temperature depends to a considerable extent on the absorptiveness of the exterior finish for infrared radiation from the sun.

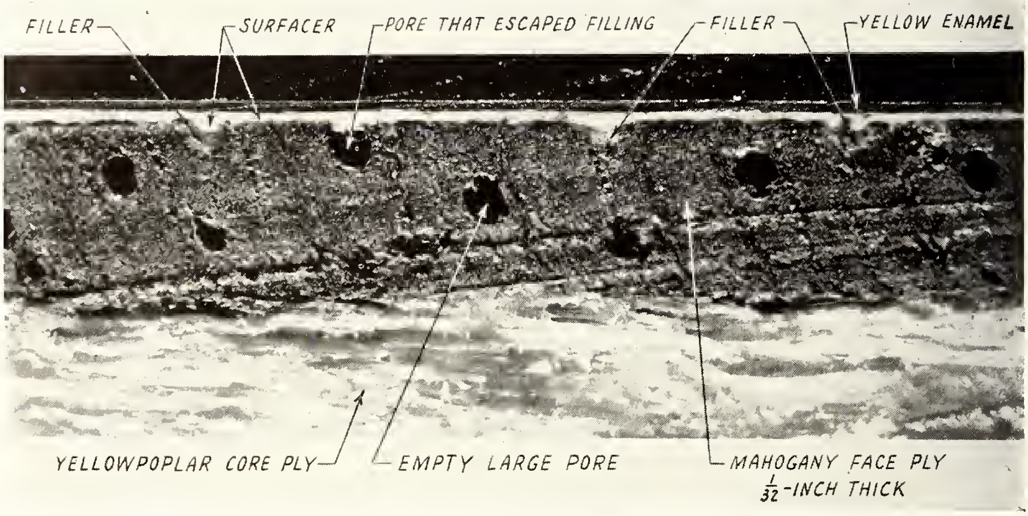

FIGURE 5-97.—Photomicrograph of a cross section through a typical enamel finish with filler and surfacer on mahogany-yellow poplar plywood. The sample was taken from an Army training plane after it had been in service some months.

White enamel or lacquer reflects most of the radiant energy of sunshine and therefore tends to keep the surface cooler than it would be with any other finish. Clear finishes, such as varnish, transmit most of the radiation, much of which is then reflected by the surface of the wood, so that the heating effect is relatively moderate. Black finishes made with carbon pigments absorb nearly all the radiation and thereby give rise to maximum heating of the surface. Colored finishes fall somewhere between white and black, according to the proportion of the radiation, particularly the infrared radiation, that they reflect. As a rule, the darker the color, the less radiation reflected and the more absorbed; hence, the colors preferred for camouflage, which are dark, tend to cause marked warming of surfaces.

Certain colored pigments that are highly absorptive of portions of visible light are reasonably highly reflective for infrared radiation. Finishes made carefully with such pigments may be dark in color and yet fairly highly reflective for infrared radiation. Ordinary olive drab camouflage enamel, for example, has a rating of approximately 10 percent for reflection of infrared radiation, but enamel of the same color can be made with a rating of 50 percent reflection.

Observations were made at Madison, Wis., in the dummy wings described in Forest Products Laboratory Mimeo. No. 1343B (*5–58*). During July 1942 with an olive-drab, camouflage-enamel exterior finish of 10 percent infrared reflectance, the maximum temperatures recorded on a clear, still day when the outside temperature in the shade was approximately 85° F. were as follows:

Position in wing	*Temperature °F.*
Upper surface of plywood	180
Outer glue line in upper plywood skin	180
Midpoints of air space between upper and lower skins	170
Glue line in lower plywood skin	130

Late in August 1942 the following comparison of temperatures in the enclosed air space was obtained when the exteriors of the plywood skins were finished with enamels of differing infrared reflectance and the outside temperature in the shade was 90° F.

Enclosed air space in wing	*Temperature °F.*
Glossy yellow enamel of 80 percent reflectance	129
Camouflage olive drab enamel of 50 percent reflectance	133
Camouflage olive drab enamel of 10 percent reflectance	138
Camouflage blue enamel of 5 percent reflectance	146

Starting early in July 1943, similar studies of temperatures were undertaken at Madison, Wisconsin, and at Tucson, Arizona, in wings from Anson bomber planes finished with a brown enamel of 10 percent infrared reflectance; meanwhile, the observations in the "dummy wings" were continued. Approximately the same maximum temperatures are developed in the real wings and in the "dummy wings" under similar conditions. The highest temperature observed in the Anson wings was 179° F. at Madison and 215° F. at Tucson, but at Madison it is believed that still higher temperatures will be attained before the experiments are concluded.

5.75. Materials for Aircraft Finishing. The materials commonly used for aircraft finishing are broadly classified into three general types, namely, dopes, lacquers, and oleoresinous products. Dopes are fabric finishes, and should be used on wood only in conjunction with fabric coverings. Lacquers and oleoresinous products, when properly made for the purpose, are suitable for finishing directly on wood surfaces. In general, lacquers should not be combined with nonlacquers in a finishing system. It is frequent practice, however, to apply an oleoresinous sealer to bare wood as the first operation in a lacquer system; with that exception it is poor practice to alternate lacquers and oleoresinous products in building a finish on wood.

5.750. Dope. Dope is essentially a solution of cellulose ester of high-viscosity grade together with a small proportion of plasticizer in suitable organic solvents and volatile thinners. This makes clear dope, which forms transparent coatings that are usually nearly colorless. To make opaque coatings of any desired color, including white and black, the necessary pigments are incorporated, making pigmented dope. The cellulose ester most widely used for aircraft dopes is cellulose nitrate (nitrocellulose) but cellulose acetate-butyrate is also used. Dopes made with the latter are less inflammable than the cellulose nitrate dopes. A primary function of dope is to tauten fabric, which it does because the dope solidifies when only a portion of the solvents and thinners has evaporated and then shrinks materially as the rest of the drying takes place. The high-viscosity grades of cellulose ester impart the desired degree of such shrinkage in drying but the high viscosity requires a very large proportion of solvents and thinners to make dopes of suitable consistency for brushing or spraying. In consequence, the nonvolatile content of dopes is very low, which means that the film formed on the surface when a single application of dope has dried is very thin. For that reason, finishing systems with dope usually require at least six or eight applications to produce a coating of satisfactory thickness. On the other hand, dope dries rapidly, hence many coats can be applied within a relatively short time.

There are three recent developments in making and handling dope that are directed toward reducing the number of applications of dope required to attach and finish fabric. In the first the fabric is "predoped"; that is, the manufacturer of dope impregnates the fabric with clear dope by means of special equipment. The predoped fabric is then shipped to the aircraft maker, who can then apply and finish it with fewer additional applications of dope. The predoped fabric is stiffer and harder to apply on surfaces with double curvature than is undoped fabric. To retain sufficient flexibility, predoped fabric often requires shipment and storage in airtight containers to keep it from drying out too much.

The second development is "hot spraying." When dope is heated and applied at 170° to 180° F. by means of specially designed spraying equipment, the dope can be made with nearly twice the usual nonvolatile content, so that one hot coat accomplishes as much as two coats of unheated dope. The process, however, requires greater skill and more careful attention of the operator.

The third development is the use of dope emulsion, which consists of specially formulated dope or lacquer emulsified in water. Such emulsions contain twice the usual content of nonvolatile and yet have a consistency suitable for brushing or spraying without being heated. The emulsion dopes or emulsion lacquers are proposed for attaching fabric to sealed plywood and then sealing the fabric to make it ready for final coats of pigmented dope, lacquer enamel, or oleoresinous enamel. The emulsion dopes facilitate the attachment of fabric even on surfaces with sharp double curvature because the water makes fabric very flexible.

Dope is low in moisture-excluding effectiveness and therefore does not make a very satisfactory protective coating for wood.

5.751. Lacquer. Lacquer is essentially a solution of cellulose ester of low-viscosity grade, together with plasticizer and resin in suitable organic solvents and volatile thinners. Pigments are incorporated in the clear lacquer to make lacquer enamels. Use of a low-viscosity grade of cellulose ester and addition of resin permit more than twice as much nonvolatile in lacquer as there is in dope, so that one application of lacquer accomplishes as much as two applications of dope in building film thickness. Most lacquers are made with cellulose nitrate, but some are made with cellulose acetate-butyrate. The aircraft lacquers generally contain more resin than cellulose ester, and the resin commonly used is one or a mixture of the alkyd (glycerol phthalate) resins, in which case the resin may serve also as a plasticizer. The lacquers take somewhat longer to dry than the dopes but are fast-drying materials nevertheless. In moisture-excluding effectiveness, the lacquers are much superior to the dopes and, if applied in coatings of equal thickness, may be nearly as good as some of the oleoresinous products. As a rule, however, lacquers are applied in somewhat thinner coatings than the corresponding oleoresinous finishes and, so applied, furnish somewhat less protection for wood.

5.752. Oleoresinous Products. The oleoresinous products when unpigmented are commonly called varnishes and when pigments are incorporated are called enamels. Varnish consists of resin blended with drying oil by heat according to a suitable cooking schedule and then, when the product has partly cooled, adding enough volatile thinner to produce the correct viscosity for application. Much less volatile thinner is required for this purpose than is the case with lacquers, hence oleoresionous products usually contain a much higher proportion of nonvolatile than lacquers do. With some of the synthetic resins, particularly the alkyds, the drying oil is incorporated during the manufacture of the resin and the "resins" so produced, which should properly be called varnishes, may be mixed with one another and thinned to make varnishes of the desired characteristics. Most oleoresinous finishes for aircraft are made with either alkyd or phenolic resins or with combinations of the two known as phenol-modified alkyd resins.

For the drying oil, tung oil is highly desired because it makes fast-drying varnishes, particularly in conjunction with the phenolic resins, but the limited availability of tung oil during wartime makes it necessary to use dehydrated castor oil, oiticica oil, and specially treated linseed oils to a considerable extent. The rate of drying and other properties of varnish depend also on the proportions of resin and drying oil. Varnishes are called "long in oil" or "short in oil" according as they are made with much or little oil for a given amount of resin. More specifically, a varnish is of "10-gallon length in oil" if it is made with 10 gallons of drying oil to 100 pounds of resin, "20-gallon length" if there are 20 gallons of oil per 100 pounds of resin, and so on. In general, a varnish dries faster and has better moisture-excluding effectiveness the shorter it is in oil, but when too short it lacks plasticity and durability. The length in oil, therefore, is commonly adjusted to give the fastest drying consistent with the required degree of durability for the use to which it is to be put. If unduly fast drying is demanded, it can be attained only by sacrificing durability.

According to their function in finishing systems, the aircraft finishing materials for wood surfaces, whether of lacquer or oleoresinous type, include sealer, wood filler, sanding surfacer, enamel, and camouflage enamel.

5.753. Sealer. Oleoresinous sealers are usually fast-drying, short oil varnishes of relatively low nonvolatile content. They are designed to sink into the cell cavities near the surface of wood and harden there without penetrating farther into the wood. Their function is to seal the surface against penetration of the liquids in coatings to be applied subsequently. Army-Navy Aeronautical Specification AN–S–17 (for sealer) and AN–C–83 (for protective coatings) require that the nonvolatile content be not less than 30 percent by weight but permit thinning the first coat to 18 percent. Since even 30 percent is too low to accomplish thorough sealing of most woods, two coats of sealer are sometimes applied before putting on other coatings.

On interior surfaces, two applications of sealer are commonly specified as a complete finishing system deemed to have sufficient moisture-excluding effectiveness for the purpose. In such cases, the second application of sealer functions as a very thin coat of varnish. Better protection would be obtained with slight added weight by using spar varnish of higher nonvolatile content (Army-Navy Aeronautical Specification AN–TT–V–118) instead of sealer for the second coat.

Sealers are comparatively new products in wood finishing for which there is at present a good deal of overenthusiasm leading to inadvisable substitution of sealer where varnish is the efficient material to use. Sealer may properly be considered a material for forming a "coating" within the surface of wood, but it is not adequately designed for forming a true coating over the surface. When a continuous unpigmented coating of appreciable thickness over a surface is required, varnish is the efficient oleoresinous material to use. One application of varnish is then roughly equivalent to two applications of sealer. Whenever more than a single application of sealer is specified, either the sealer is inadequately formulated to accomplish its purpose efficiently or sealer is being used where varnish would be a more suitable choice.

Sealers may be clear—that is, without pigments—or they may contain moderate proportions of such pigments as silica and magnesium silicate (liquid wood filler, described farther on, contains larger proportions of pigments). The pigmented sealers tend to be somewhat more effective than the clear sealers, both in sealing and in moisture-excluding effectiveness, but they are slightly heavier and less convenient for application by dipping because the pigments tend to settle in the dip tank.

According to specification AN–S–17, the first application of sealer on bare wood may be by brushing, dipping, or roll-coating but not by spraying. For the second application on interior surfaces, the sealer may be applied by spraying, brushing, or dipping. Specification AN–S–17 describes both clear sealers and "pigmented sealers," but by "pigmented sealer" it means liquid wood filler.

5.754. **Wood Filler.** Wood filler is essentially a highly pigmented sealer designed to fill and level off the large pores in hardwoods having pores as large or larger than those in birch. The pigments are commonly silica and magnesium silicate or similar pigments of low opacity. Filler may be furnished in the consistency of paste to be thinned before application or it may be furnished ready for application. Filler may be applied by brushing, spraying, or mopping; but in any case, after much of the volatile has evaporated but before the rest has hardened, it is wiped with rag, burlap, or moss across the grain of the wood to pack the large pores and remove any excess.

Filler when used should be applied to bare wood before any other finishing material is put on. A good filler, properly applied, serves both as sealer and filler; nevertheless, a clear sealer is sometimes applied before or after wood filler. Application of sealer before filler interferes with proper packing of the filler into the large pores of the wood and therefore is not considered good practice. If sealer is used at all in conjunction with the filler, the filler should be applied first and the sealer afterward. Specification AN–S–17 covers liquid wood filler (ready for application). Federal Specification TT–F–336a covers paste wood filler.

5.755. **Sanding Surfacer.** If a finish of mirrorlike smoothness is required on wood, it is necessary to apply a coating of substantial thickness that can be sanded soon after it is dry to provide a perfectly level foundation for enamel or lacquer enamel. Ease of sanding is achieved by making sanding surfacers with a very high proportion of pigments so that the coating, as soon as the volatile thinner evaporates, is somewhat porous and spongy. The pigments used, such as magnesium silicate and china clay, are largely of low opacity, but enough opaque pigment, such as titanium dioxide, is commonly incorporated to give the coating good opacity. For aircraft uses, sanding surfacers are usually either white or gray in color. Army Air Forces Specification 14115 covers "Surfacer; Aircraft (for wood)."

Inclusion of surfacer in a finishing system adds materially to the weight of coating without proportionately improving either the protective value or the durability. The film of surfacer is too porous to contribute much protection, and it is inclined to become brittle as the finish ages.

5.756. **Patching Putties.** Patching putties are essentially surfacers put up in putty consistency for application with a putty knife or with the fingers to fill and level any holes, cracks, or other blemishes in the surface. The nail holes left after strip-nail gluing, for example, unless satisfactorily filled with wood filler, must usually be puttied before finishing enamel is applied.

5.757. **Enamel.** Although pigmented sealer, wood filler, and sanding surfacer are really forms of enamel, the term "enamel" when not otherwise qualified is usually reserved for the product used for the final coat (finish coat) of a finishing system. Enamels may be gloss, semigloss, or lusterless. The lusterless enamels for aircraft and other war material are called camouflage enamels. The gloss enamels contain only enough pigment, chiefly or entirely opaque pigment, to give them adequate hiding power and color and good working properties. The coating left after application and escape of the volatile thinners contains enough drying oil and resin to fill all interstices between pigment particles and, in addition, to leave a film of clear material over the surface, which provides the high degree of gloss. The semigloss enamels contain more pigment, some of which is usually pigment of low opacity (extending pigment) so that the dried coating contains barely enough drying oil and resin to fill the interstices between particles of pigment. The camouflage enamels contain still larger proportions of pigment, largely pigments of low opacity, so that the dried coating contains insufficient oil and resin to fill the interstices between particles of pigment, and the surface is therefore left slightly rough. Light is reflected diffusely rather than specularly from such a surface, making the surface lusterless, but the coating itself is necessarily somewhat porous and spongy and allows moisture to pass through it too readily to provide appreciable protection for wood.

The relative proportions by volume of volatile ingredients, v; nonvolatile ingredients, $1-v$; pigment, p, and the ratio of pigments to nonvolatile ingredients, $p/(1-v)$, differ among camouflage enamel, gloss enamel, gloss lacquer enamel, and gloss-pigmented dope as indicated by the representative data in table 5–19.

TABLE 5–19.—*Relative proportions by volume of ingredient per gallon of product ready for application for 4 finishes*

Finish	Volume of ingredient per gallon of product ready for application			Ratio $p/(1-v)$
	Volatile solvents and thinners v	Total nonvolatile (pigment, drying oil and resin) $(1-v)$	Pigment p	
	Gallon	*Gallon*	*Gallon*	
Camouflage enamel	0. 50	0. 50	0. 30	0. 60
Gloss enamel	. 50	. 50	. 10	. 20
Gloss lacquer enamel	. 75	. 25	. 04	. 16
Gloss pigmented dope	. 90	. 10	. 01	. 10

5.76. Aircraft Finishing Systems. Although the Forest Products Laboratory has developed basic principles of wood finishing in many fields (*5–56*), it has not studied aircraft finishing long enough to make its own recommendations of suitable systems. Accordingly, the systems described herein are those set forth as minimum requirements in Army-Navy Aeronautical Specification AN–C–83. Although a number of optional finishing systems are authorized by Specification AN–C–83, it is provided that only one system may be used for a given class of surfaces of any specific model of aircraft.

5.760. Interior System A. For interior surfaces not exposed to view, such as interior surfaces of wings, the minimum finish now specified consists of two applications of sealer conforming to Army-Navy Aeronautical Specification AN–S–17.

Operation 1: Apply by brushing or dipping 1 coat of sealer and allow to dry for not less than 6 hours at room temperature or not less than 30 minutes at 130° to 150° F. The sealer may be thinned with aromatic naphtha, Type I, Grade B, of Specification AN–VV–N–96. The surface must not be sanded after the sealer has dried.

Operation 2: Apply "by any commercial method producing a wet film" 1 coat of sealer. Any thinning of the sealer must be the "minimum consistent with the method of application." If drying is at room temperature, the work is ready to handle in not more than 6 hours; if dried at 130° to 150° F., it is ready to handle in 30 minutes.

Wood filler is not required.

The weight added by application of Interior System A should be not less than 1.5 nor more than 3.0 ounces per square yard (0.01 to 0.021 pound per square foot). Even the minimum represents more generous application of sealer than has been the practice of some aircraft manufacturers.

5.761. Interior System B. The degree of protection afforded by System A, even when applied at the maximum weight, is not great. For extra protection on such surfaces as wheel wells and surfaces of hulls below the floor boards, the minimum acceptable finish is System B, as follows:

> *Operations 1 and 2:* Same as in System A.
>
> *Operation 3:* Apply another coat of sealer as in Operation 2.
>
> *Operation 4:* Mix 12 to 16 ounces of aluminum paste conforming to Specification AN–TT–A–461 with one gallon of sealer. Apply 1 coat of the mixture by brushing, spraying, or dipping. The same time is allowed for drying as for Operation 2.

5.762. Interior Surfaces Exposed to View. The minimum finishing systems for interior surfaces exposed to view are the same as those specified for exterior surfaces when not covered with fabric except that on interior surfaces the application of wood filler on woods with large pores, such as mahogany, is optional, not mandatory. There are, however, a number of options, and it is not necessary to select the same option for both the interior exposed surfaces and the exterior surfaces of a given model of aircraft. Interior exposed surfaces, for example, may be finished with a lacquer system, whereas an enamel system or a fabric and dope system may be used on the exterior surfaces.

The weight added by application of finish to interior exposed surfaces should be not less than 3.0 nor more than 7.5 ounces per square yard (0.021 to 0.052 pound per square foot).

5.763. Areas of Contact Between Metal and Wood. Areas of contact between metal and wood should be protected with varnish conforming to Specification AN–TT–V–118, with aluminized bituminous paint conforming to Specification AN–P–31, or with other materials approved by the procuring agency. The number of coats is not provided in Specification AN–C–83, but at least two coats of varnish are necessary to afford much protection, though one heavy coat of aluminized bituminous paint may suffice. Bituminous paint, however, may not be used where surfaces may come in contact with gasoline, with additional paint coatings, or with personnel.

5.764. Exterior System C (Enamel). The minimum system for exterior surfaces when not covered with fabric and when it is desired to use oleoresinous enamel for the finish coat consists of System A plus one coat of enamel. The enamel must conform to Specification AN–E–3 in the color required by the procuring agency when a gloss finish is specified and to Specification AN–E–7 in the required color when camouflage finish is specified.

> *Operations 1 and 2:* Same as in System A.
>
> *Operation 3:* Apply by spraying or brushing 1 coat of enamel. The enamel may be thinned as required for good application with not more than one-fourth its volume of mineral spirits conforming to Federal Specification TT–T–291 for gloss enamel, or of aromatic naphtha, Type I, Grade B, of Specification AN–VV–N–96 for camouflage enamel. Gloss enamel dries at room temperature within 18 hours, camouflage enamel within 1 hour. Some gloss enamels dry at 130° to 150° F. within 2 hours.

On woods with pores larger than those in birch, such as mahogany, System C is unacceptable because it does not make the surface smooth enough. Either of two optional modifications must be followed. Under the first option, a coat of liquid wood filler may be applied "in addition to the two sealer coats." The normal place to apply filler is prior to Operation 1, but Specification AN–C–83 permits the application of filler and sealer in any sequence approved by the procuring agency. Under the second option, sanding surfacer may be applied between Operations 2 and 3. The Specification provides that "when surfacer is used the processing shall be so controlled as to leave a minimum thickness of the surfacer consistent with acceptable smoothness."

5.765. Exterior System D (Lacquer Enamel). When lacquer enamel is used for the finishing coats, the minimum system requires that two coats of lacquer enamel be used to replace the one coat of oleoresinous enamel in System C. Gloss lacquer enamel must comply with Specification AN–TT–L–51 and camouflage lacquer enamel with AN–L–21.

Operations 1 and 2: Same as in System A.

Operation 3: Apply by spraying 1 coat of lacquer enamel. The lacquer enamel may be thinned with not more than half its volume of lacquer thinner conforming to Specification AN–TT–T–256. At least 40 minutes should be allowed for drying. The surface may then be sandpapered lightly if necessary.

Operation 4: Apply by spraying 1 coat of lacquer enamel. The lacquer enamel may be thinned with not more than half its volume of lacquer thinner conforming to Specification AN–TT–T–256. At least 40 minutes should be allowed for drying.

On woods with pores larger than those in birch, System D requires one of the two optional procedures already described in connection with System C, namely, use of liquid wood filler or of sanding surfacer in addition to the two coats of sealer in order to obtain a smoother surface.

The weight added by application of finishing System C or D should be not less than 3.0 nor more than 7.5 ounces per square yard (0.021 to 0.052 pound per square foot). The upper limit should be approached only if sanding surfacer is used.

5.766. System E for Floats and Hulls. Specification AN–C–83 provides that "exterior surfaces of floats and hulls below a line 12 inches above the full load water line shall be finished with 4 coats of sealer and a hull-bottom finish system as specified by the procuring agency."

5.767. Fabric Covering Over Plywood. The practice of covering exterior surfaces of plywood with fabric and then finishing with dope offers the following advantages:

1. It follows a finishing procedure with which most aircraft manufacturers have had long experience and for which their plants are adequately equipped.
2. Edges of plywood and joints between face veneers or sheets of plywood can be covered smoothly with little danger of premature cracking of the finish at the edges or over the joints.
3. Any checking that develops in faces of plywood usually remains concealed.
4. Presence of the fabric imparts greater resistance of the finish to abrasion, for example, by sand thrown up during landing and take-off.
5. When finish must be renewed, the old fabric and dope can be stripped off completely so that new finish can be applied without increase in weight.

The chief disadvantages of the fabric and dope finish are excessive weight, the low degree of protection furnished for the wood, and comparatively low durability.

Specification AN–C–83 includes the requirements of cotton fabric for covering plywood where no portion of the loading is carried by the fabric. Predoped fabric is permitted, in which case it must be applied in accordance with the directions of the manufacturer.

5.768. Finishing System F (Fabric and Cellulose-nitrate Dope). Operations specified for applying fabric and cellulose-nitrate dope are:

Operations 1 and 2: Apply two coats of sealer over the plywood as in System A.

Operation 3: Apply by brushing or spraying 1 coat of dope conforming to Specification AN–TT–D–514. Thin the dope as required with thinner conforming to Specification AN–TT–T–256. The dope may be colored slightly as a guide in application, provided that it is not made opaque. Allow 1 hour for drying.

Operation 4: Repeat Operation 3.

Operation 5: Lay the fabric in place and, if desired, tack it lightly. Set it in place by brushing in one direction with dope thinner or with thinned dope ("pull-over solution"). Release any air bubbles imprisoned under the fabric by puncturing with pins if necessary. Allow 1 hour for drying.

Operation 6: Apply by brushing 1 coat of uncolored dope (Specification AN–TT–D–514) thinned as required to wet the fabric thoroughly and produce maximum adhesion. Allow 1 hour for drying.

Operation 7: Apply fabric tape over all unstitched fabric joints and over all exposed nail and screw heads. Lay the tape on wet dope and cement in place with thinned dope. Allow 1 hour for drying.

Operation 8: Repeat operation 6, except that the dope may be applied by either spraying or brushing.

Operation 9: Repeat Operation 8.

Operation 10 (optional): Sand lightly with paper not coarser than No. 280 if necessary to smooth out the nap of the fabric.

Operation 11: Apply by spraying or brushing 1 coat of pigmented dope of the color and degree of gloss specified by the procuring agency. For spraying, the dope may be thinned with not more than its own volume of thinner conforming to Specification AN–TT–T–256. For brushing, the thinner must not exceed one-fourth the volume of the dope. Allow 1 hour for drying.

Operation 12: Repeat Operation 11.

The dope for Operations 11 and 12 may be, as specified by the procuring agency, gloss pigmented dope conforming to Specification AN–TT–D–554, aluminized dope conforming to Specification AN–TT–D–551, or camouflage dope conforming to Specification AN–D–8. The aluminized dope is supplied as a clear vehicle to be mixed on the job as follows: Add approximately 12 ounces of aluminum paste conforming to Specification AN–TT–A–461 to 1 pint of the clear dope, stir thoroughly, then add enough clear dope to bring the total volume to 1 gallon, and finally thin as described in Operation 11.

5.769. Finishing System G (Fabric and Cellulose-acetate-butyrate Dope).

Operations 1 to 7: Same as in System F, both as to materials and procedure.

Operation 8: Apply by spraying or brushing 1 coat of clear butyrate dope conforming to Specification AN–D–1. The dope may be thinned as required for good application, using thinner conforming to Specification AN–TT–T–256. Allow 1 hour for drying.

Operation 9: Repeat Operation 8.

Operation 10 (optional): Sand lightly with paper not coarser than No. 280 if necessary to smooth the nap of the fabric.

Operation 11: Apply by spraying or brushing 1 coat of pigmented butyrate dope conforming to Specification AN–D–2 if the procuring agency requires gloss finish or Specification AN–D–3 if camouflage finish is required. The dope may be thinned as necessary for good application. Allow 1 hour for drying.

Operation 12: Repeat Operation 11.

The weight added by finishing System F or G should be not less than 4.5 nor more than 7.0 ounces per square yard (0.031 to 0.052 pound per square foot) exclusive of the fabric, which weighs not more than 3.5 ounces per square yard (0.024 pound per square foot) in addition.

5.7690. Insignia. The application of insignia after the exterior finish has been otherwise completed is described in Specification AN–I–9.

5.77. Methods of Applying Finishes. As a rule, all major finishing operations that involve application of large quantities of finishing materials should be performed in a finishing room separated from the rest of the factory and used only for finishing operations. The room should be maintained in a neat and orderly manner, with particular care to keep it free from dust and to minimize fire hazards. Good ventilation is essential. Oleoresinous finishes require oxygen from the air for drying, and lacquers and dopes demand movement of air ample to carry off the large volume of solvents and thinners given off as they dry. Accumulation of such vapors constitutes both a fire and a health hazard. Positive ventilation by forced draft, sufficient to effect at least 15 complete changes of air per hour, is highly desirable if not essential in finishing rooms in which much dope or lacquer is applied. Incoming air should be freed from dust by passing it through cheesecloth, very fine mesh screen, or other suitable filters.

The temperature of the finishing room should not be lower than 70° F. and should be held as uniform as practicable. Finishing materials become heavier in viscosity at lower temperatures and thinner at higher temperatures. Although some adjustment can be made by altering the proportion of thinner, uniform temperature promotes uniform application and uniform rate of drying of finishing materials. The optimum relative humidity in the finishing room is approximately 60 percent. At 70° F. this tends to hold wood in the range of 10 to 12 percent moisture content, and under such conditions finishes dry satisfactorily. If the relative humidity is too high, coatings tend to remain tacky for a long time and dopes and lacquers may be damaged by "water blushing" during application. (Blushing is a condition of whitening of a coating caused either by a separation of some of the vehicle constituents or by droplets of water emulsified in the coating before it has dried.)

In the winter season, air conditioning of the finishing room can be accomplished easily and economically by heating the incoming air to 70° F. and raising its relative humidity to 60 percent by means of steam jets or other convenient devices. Under summer conditions, however, cooling and dehumidification of the large volume of air required present serious difficulties, especially in places where cold water in large volume is unavailable. In spite of its difficulties, air conditioning during summer weather is exceedingly helpful in regions where the relative humidity may rise much above 60 percent, because blushing may then prevent all application of dope or lacquer until the weather changes. Where there is no provision for dehumidification and difficulty with blushing arises, the relative humidity can be lowered by raising the temperature of the finishing room still higher insofar as that is practicable.

Spraying is the principal method used to apply aircraft finishes, but for certain operations brushing is believed to give better results or is more convenient, and for still others dipping is practiced. Less frequently used methods are roll coating in equipment much like glue spreaders, mopping on with rags or suitable applicators (sealers and fillers), wiping off with rags or other material (fillers and sometimes sealers), and knifing with putty knife or spatula (surfacers and putties).

5.770. Spraying. Spraying is a rapid method of application especially effective when applying very fast-drying products on large surfaces. Spraying can be done only in spray booths or spray rooms equipped to exhaust the mist and fumes; hence the work must be brought to the spray booth. In most States there are detailed laws governing equipment and safety precautions for industrial spray finishing. Technical details about the equipment needed for specific operations are obtainable from manufacturers of spray equipment. For hot spraying, special equipment is required.

Typical spray booths for aircraft finishing are shown in figures 5–98 and 5–99.

5.771. Brushing. Brushing is used for small jobs along the assembly line where it is more convenient to bring the finishing materials to the part than to take the part to a spray booth.

A few operations are better done by brushing than by spraying. The first coat or two of dope are usually brushed on fabric, because the pressure of the brush on the fabric brings about better penetration and helps to release air bubbles. Many finishers believe that sealers and fillers can be applied on wood more effectively by brushing than by spraying, but this view is not accepted everywhere.

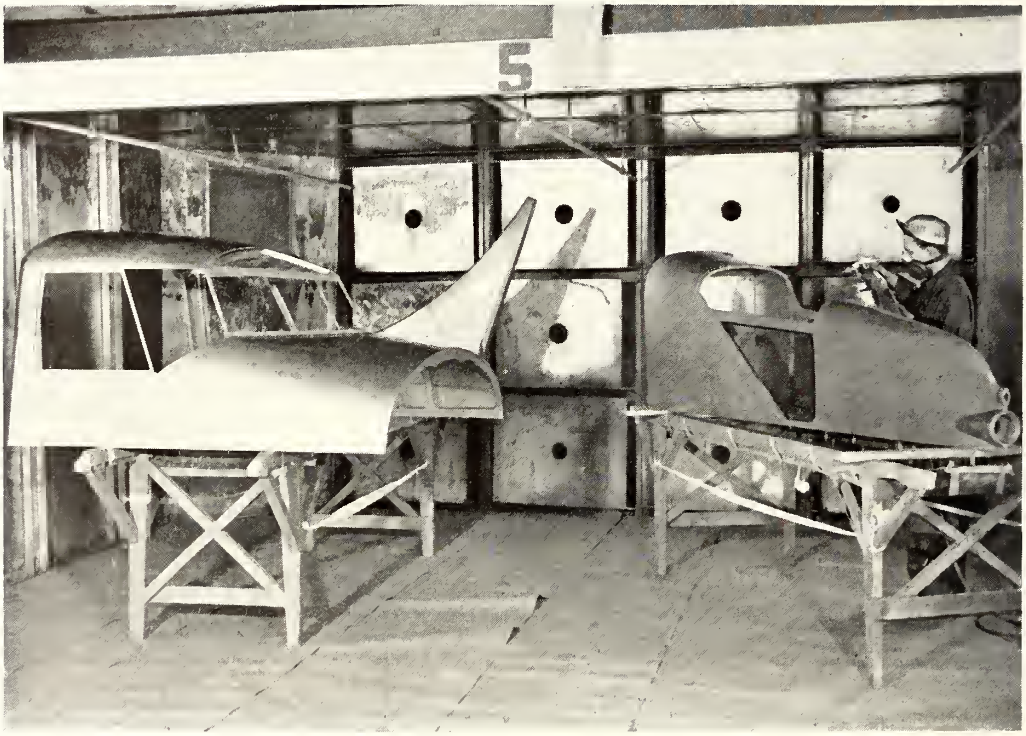

FIGURE 5–98.—Typical spray booth for finishing aircraft parts by spraying. The operator wears a mask for protection against paint mist.

5.772. Dipping. Dipping is a method of rapid application that permits application of finish to interior parts inaccessible to brush or spray. Figure 5–100 shows a plywood-covered wing section being dipped in sealer to finish all of the interior surfaces and seal the outside surfaces in a single operation. After each dip the excess sealer is wiped from the outside surfaces with rags wetted with thinner.

Figure 5–101 shows the dipping of a wing section that is to be subsequently covered with fabric. The surfaces in this case might be accessible for spraying, but dipping is faster and insures more certain penetration of the finish into pockets like those formed between rib caps, diagonal braces, and gussets.

The tank shown in figure 5–100 holds 2,000 gallons of sealer, the composition of which must be checked frequently to restore thinners gradually lost by evaporation and to avoid "livering" (coagulation forming a jelly) of sealer that remains in the tank long enough to become seriously oxidized. Pigmented products are more difficult to apply by dipping than are clear products because the pigments tend to settle, making it necessary to provide agitation to keep them in suspension.

5.773. Forced Drying. Drying time can often be greatly reduced by raising the temperature moderately. A typical oleoresinous exterior finishing system, consisting of sealer, surfacer, and 2 coats of gloss enamel, which requires 23 hours of drying time at 70° F., can be dried in 4¾ hours in the forced drying room shown in figure 5–102 at a temperature of 130° F. and a relative humidity of 30 percent.

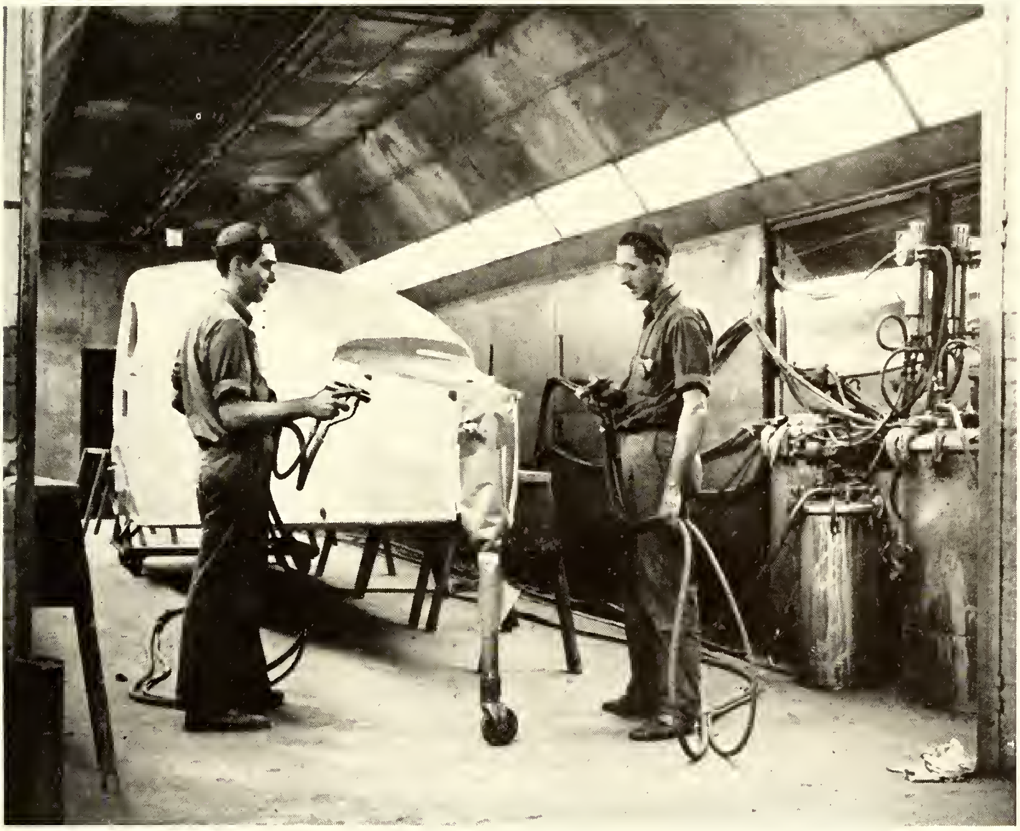

FIGURE 5–99.—Spraying a fuselage in a spray booth. Note how parts not to be sprayed are masked with paper held in place with masking tape.

Where the work progresses through the finishing room on dollies such as that shown in figure 5–103, it is not difficult to make use of forced drying.

For wood finishing, drying-room temperatures are limited. A too sudden increase in temperature may cause blistering of coatings resulting from expansion of the air in the wood and excessive drying of the wood, which must be avoided. Humidification of the drying room prevents inordinate drying of the wood but, if the relative humidity control is set too high, cold wood entering the drying room is far below the dew-point temperature and water therefore condenses upon it to the detriment of the finish. At 130° F., a relative humidity of 65 percent would be needed to keep wood at 10 percent moisture content; but the dew point is then 114° F., far above the temperature of the finishing room and the temperature of finished parts entering the drying room from the finishing room. Serious condensation therefore occurs. Experience has shown that 130° F. and 30 percent relative humidity in the drying room are suitable provided that the temperature of the finishing room and of the finished parts is not allowed to drop below 70° F. Although the dew point for 130° F. and 30 percent relative humidity falls at 88° F. the finished surfaces evidently reach that temperature before condensation takes place. Under the conditions in question the wood loses less than 2 percent of its moisture during forced drying of a system that requires 4¾ hours.

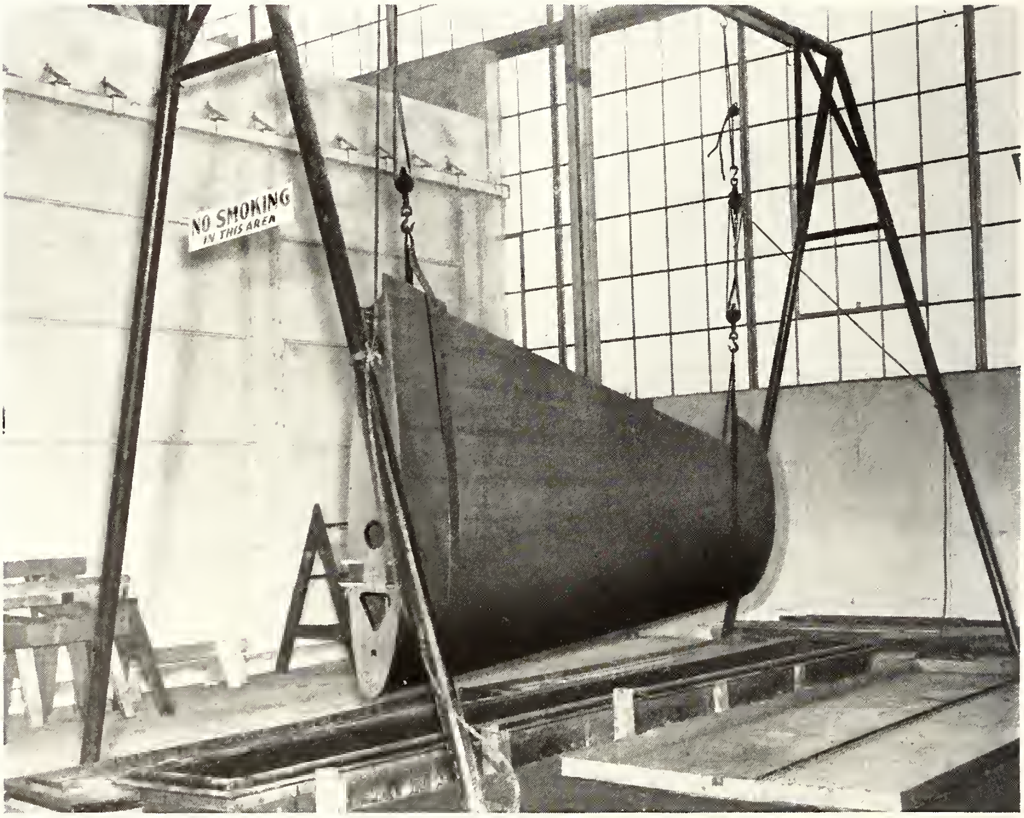

FIGURE 5–100.—Dipping tank set in floor of finishing room holding about 2,000 gallons of varnish sealer in which plywood-covered wing sections are dipped twice to finish all interior surfaces and seal the outside surfaces.

5.78. Special Problems Arising from Construction Procedures. Several special problems of finishing arise from necessary procedures in the manufacture of aircraft.

5.780. Finishing Surfaces Inaccessible After Assembling. The interior surfaces of plywood-covered wing sections are usually inaccessible after the plywood covering has been glued on both sides, yet Specification AN–C–83 requires that all of the interior surfaces including the inside faces of the plywood covering receive protective finish.

One method of complying with these requirements is to complete all gluing before any finish has been applied and then to apply the required two coats of sealer by dipping the wing as shown in figure 5–100. The vent holes in the bottom skin, inspection ports, and lightening holes admit sealer within the wing, allow the enclosed air to escape, and then permit excess sealer to drain out after lifting the wing from the dip tank. A variation of the method is to hold the wing in a suitable device for rocking and rotating it, pour an abundance of sealer inside through a convenient opening, slosh the sealer around inside until all surfaces are believed coated, and then drain out the excess sealer. Neither procedure admits of adequate inspection of the interior surfaces after finishing to see that no areas have been skipped and no puddles of excess material have been left behind.

Another method of meeting the requirements of Specification AN–C–83 is to complete the assembly to the point at which the plywood skin has been glued on the top or the bottom of the wing and the second skin has been cut and fitted accurately but has not yet been glued down. All glue lines for attaching the second skin must then be located, marked off, and protected from contamination with finish either by covering them temporarily with masking tape or by special care in applying finish. Finish may then be applied to all interior surfaces except the glue lines and allowed to dry. The masking tape, if used, is then removed and the second skin is carefully glued in place. This procedure obviously is slow and laborious and fails to apply protective finish at the edges of glue lines between rib and spar caps and the second skin. Any creeping of finish into glue lines or inaccuracy in locating and adjusting glue lines may produce weak glue joints. Another variation of the procedure that permits somewhat faster production is to assemble to the point at which one skin has been glued in place, apply finish to the interior surfaces of the assembled portion and let it dry, cut and fit the second skin, spread glue

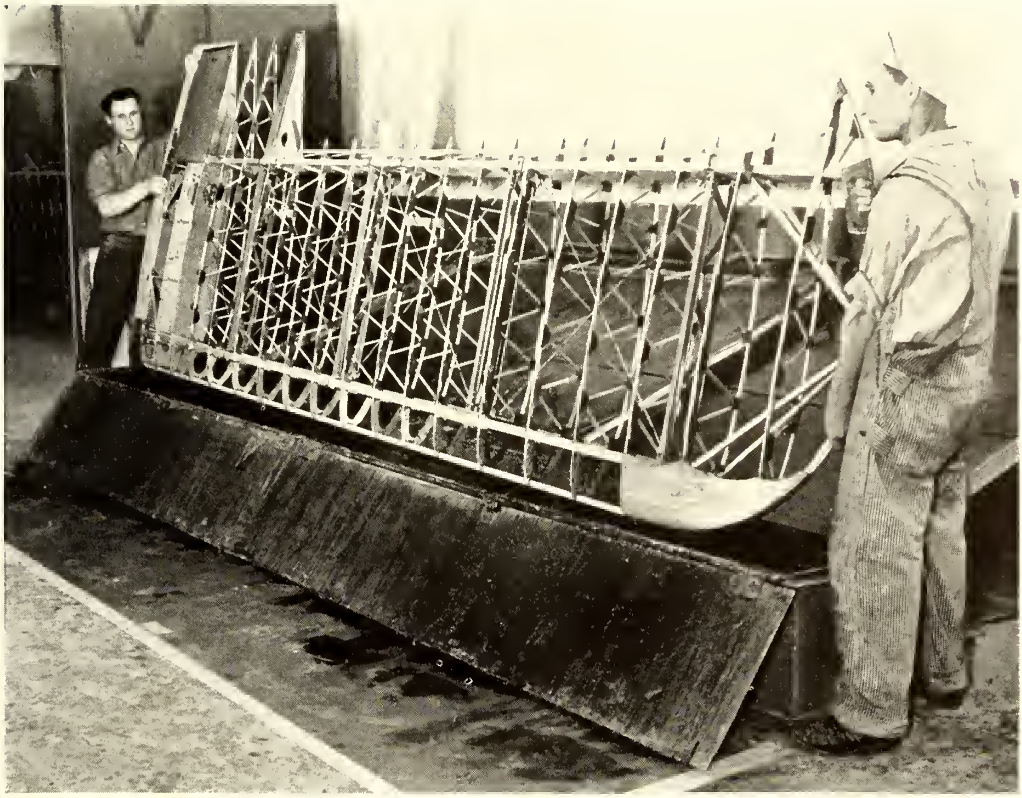

FIGURE 5–101.—Dipping tank set in floor of finishing room showing method of finishing woodwork of wing section later to be covered with fabric as seen in figure 5–103. Note drain rack in background.

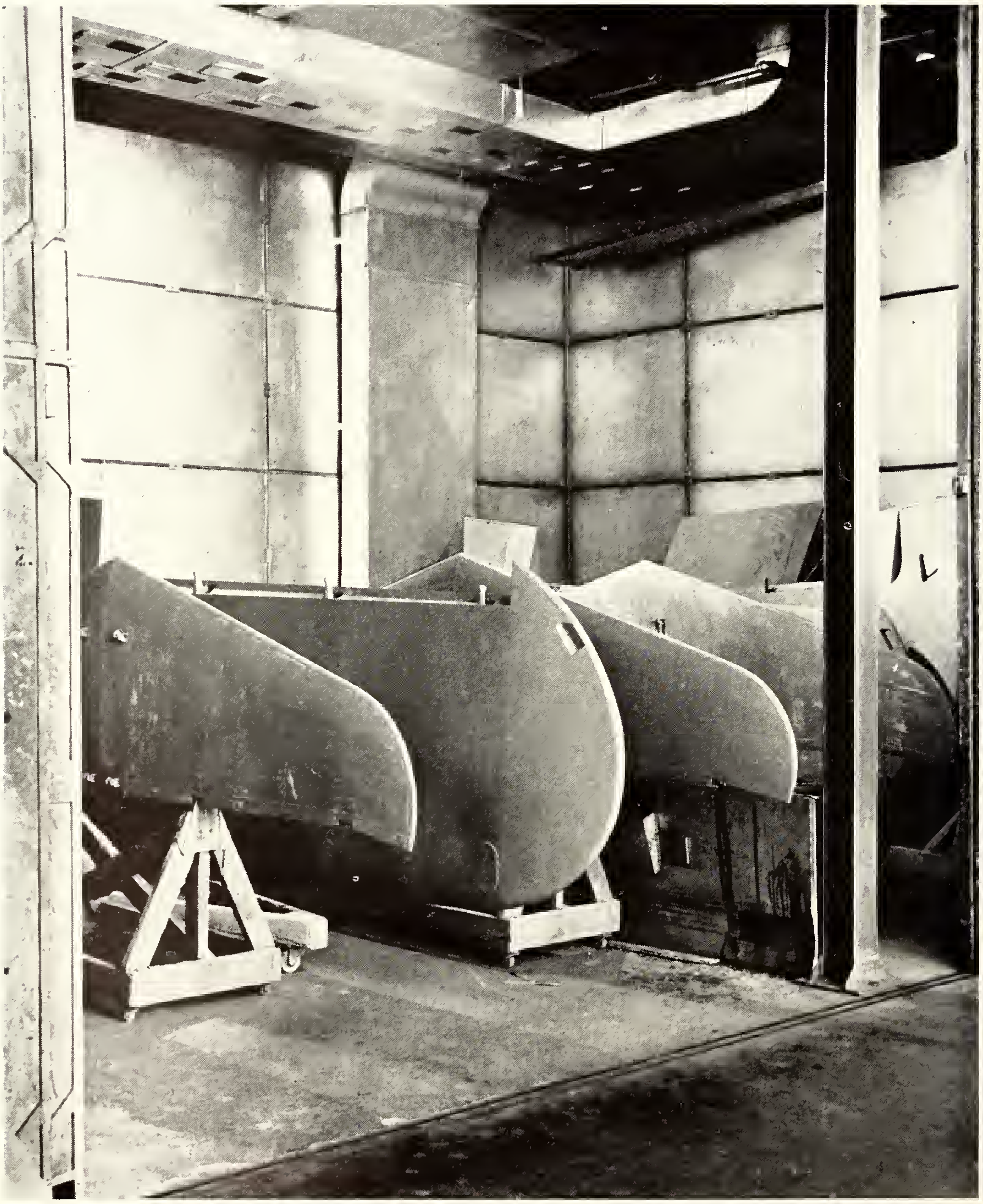

FIGURE 5-102.—Typical drying room for forced drying of aircraft finishes at 130° F. dry bulb, 97° F. wet bulb (30 percent relative humidity).

on the rib caps and spar caps, place the skin in position just long enough for some of the wet glue to cling to the skin to mark the glue lines, remove the skin and apply interior finish by hand, and then complete the gluing while the interior finish is still wet. This procedure encourages contamination of the glue with sealer, admits of one coat only of sealer on the second skin, and prolongs the assembly time to the point at which the glued joints are of doubtful quality.

Some scalers are much more nearly gluable than heretofore considered possible, particularly when the gluing is done with low-temperature, phenolic-resin glues. No sealer has yet been found, however, that the Forest Products Laboratory considers reliably gluable for aircraft purposes. Efforts have been made to use resin glues for the dual purpose of providing protective finish for interior surfaces and gluing plywood skins in place. Some resin glues when thinned and applied as plywood coatings weighing 0.02 to 0.03 pound per square foot afford sufficient moisture-excluding effectiveness to meet that requirement of Specification AN–S–17 and leave a surface that can be glued firmly; but the interior finishes so produced are brittle and inclined to craze.

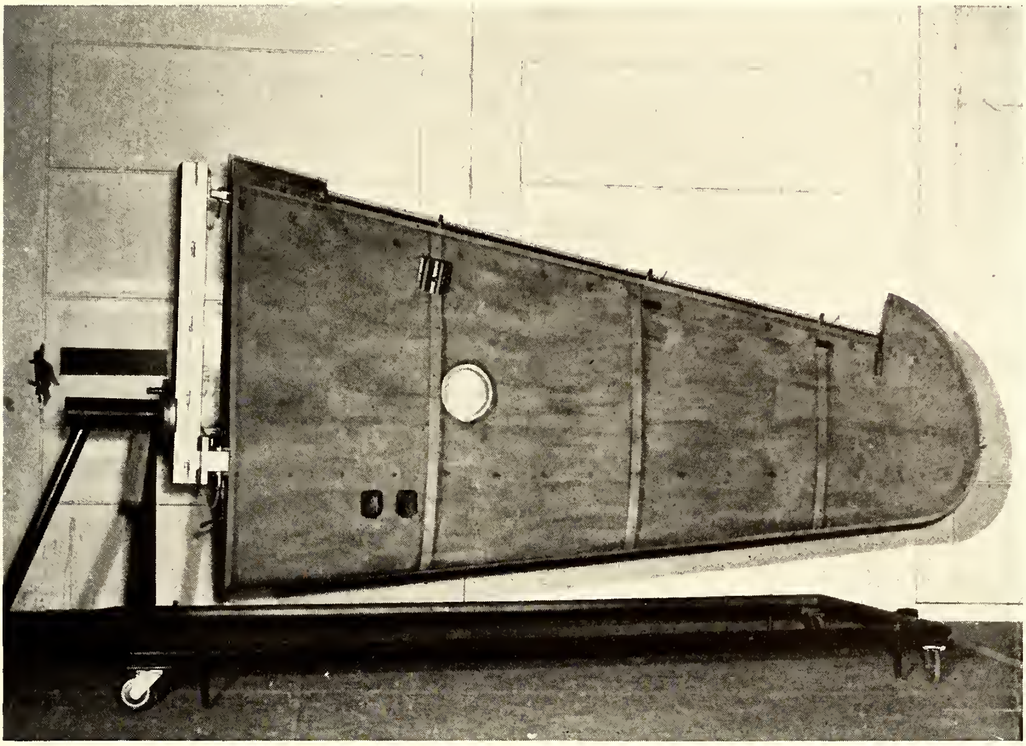

Figure 5-103.—Fabric-covered wing section after applying clear dope. The clear dope contains a little blue dye for identification in the factory. Note the dolly on which the wing section is moved through the various steps in finishing.

A practice followed for some time in the construction of some Canadian and British airplanes but not admissible under Specification AN–C–83 is to apply no finish whatever to the interior surfaces of top skins. In manufacture, the bottom skin is glued to the frame first, after which protective finish can be applied readily to the inside of the bottom skin and to the ribs and spars for a distance approximately two-thirds of the way toward the top. The top skin, with no finish at all, is then glued in position. Since any free water that gets into enclosed spaces will drain down over the bottom surface to the vent holes and the top skin is repeatedly warmed and dried by exposure to sunshine, this procedure offers a reasonable compromise by supplying protective finish at those points where it may be most useful and avoiding the bottle-neck in assembly imposed by the requirement of finish on all interior surfaces.

5.781. Glue Squeeze-out and Other Contaminants. The incompatibility between glues and finishes affects finishes adversely when applied over glue squeeze-out or other contamination of the surface with glue. On interior enclosed surfaces, the nature of the gluing operations makes it difficult to minimize squeeze-out and inaccessibility makes it hard to remove the excess glue subsequently. It is customary to apply interior finishes on enclosed surfaces directly over any glue squeeze-out that may be present even though it is realized that the hardened glue and finish often chip off in service, leaving a portion of the wood unprotected.

On interior exposed surfaces and on exterior surfaces every practical effort should be made to prevent excessive squeeze-out during gluing. Specification AN–C–83 requires that such surfaces be free from squeeze-out extruded more than one-eighth inch beyond joints. Even one-eighth inch of glue, however, is enough to cause premature failure to finish over the glue, and the failure may then spread farther over the surface. Light sanding of areas contaminated with glue, enough to expose clean wood fibers for contact with the finish, is permitted.

Other foreign substances soiling surfaces to be finished, such as oil or grease, are objectionable and should be removed as completely as possible. Naphtha may be used to sponge off oil or grease, but it should be applied first around the circumference of the soiled area, working in toward the center, in order to avoid spreading the oil or grease over a still larger area. At best, the contaminants can be removed only in part, hence the most effective precautions are those that prevent soiling of the surfaces in the first place.

Care should be exercised in the choice of materials for placing inspector's markings, part numbers, batch numbers, and other control information on areas that may become parts of the surfaces to receive finish. As far as practical such markings should be placed on faces that will ultimately be concealed from view, but in any case the marking material should be one that will not harm finishes. Grease-pencil and lumber-marking crayons containing wax are harmful. Ordinary soft graphite pencils and common stamp-pad inks made with water-soluble dyes may be used safely.

Surfaces to be finished should be free from dust, sander dust, dirt, or other foreign solids. Sawdust, shavings, chips, and loosened glue squeeze-out should be removed from enclosed spaces before they become inaccessible. An air spray is useful for such cleaning but a vacuum cleaner is better and an old-fashioned tack rag (a rag made sticky with partly dried oil or varnish) still better.

5.782. Exposed Edges of Plywood and Other End Grain Wood. Good design will minimize exposure of plywood edges and butt joints by scarfing or other details of construction. There may often be some edge exposure, however, at vent holes, inspection holes, and fittings.

Taping of exposed edges is probably the safest procedure for providing effective protection of both the wood and the finish. Holes too small for taping, such as vent holes, can be closed with metal or plastic grommets. Specification AN–C–83 requires that end-grain edges on interior parts receive at least two coats of sealer (system A) and, on exterior parts, at least three coats of sealer unless they are to be covered with doped fabric. Clear sealers, however, are not very effective on end-grain wood. Highly pigmented sealers are more effective.

For end-grain surfaces and drilled holes in wood spars and other primary structural members, Specification AN–C–83 requires that the surface be sanded smooth and finished with two coats of sealer plus one coat of aluminized varnish conforming to Specification AN–P–31, except that the bituminous paint may not be used on surfaces to receive additional coats of finish or that may come in contact with gasoline or with personnel.

5.783. Nail Holes or Nail Heads. Flush-driven nails or screws left in exterior surfaces to be finished are likely to prove points of premature failure of the finish. The finish usually cracks over the junction of wood and metal and the failure progresses from the crack. Specification AN–C–83 requires that nail or screw heads be taped after application of sealer.

Nail holes left from nail-strip gluing or countersunk nails or screws should be filled before further finish is applied. Holes in woods on which wood filler is applied should be filled sufficiently to protect the wood and the durability of the finish, but filler alone will not make them level enough to be entirely concealed from view. Very small holes may be leveled after the application and sanding of a surfacer, but larger ones will still appear as slight depressions. If such slight depressions are considered objectionable enough to require further leveling, they must be puttied by hand with a quick-drying putty that is known to be compatible with the finishing system. As a rule, however, a more durable finish may be expected if the puttying is omitted and the slight depressions over the holes allowed to remain visible.

On woods having no pores large enough to require wood filler, and where slight depressions in the finish over nail holes will be acceptable, wood filler may be applied over the areas in which there are nail holes only. This may be done most easily on the bare wood before sealer is applied.

5.784. Effect of Seams in Plywood Faces. When seams in face veneers of plywood have been well glued with water-resistant glue, they have no effect on the behavior of finish. The finish should remain as intact over the seam as it does over the parts of the surface having no seams, except where glue squeeze-out occurs.

Unglued seams are likely to cause cracking of the finish. The thicker the face ply, the earlier the cracking may be expected to set in, and the wider will be the crack formed. Where the face ply is no thicker than one thirty-second inch, cracking of the finish, though readily visible, may not represent too serious an impairment in the durability of the finish. If it is considered necessary to prevent such cracking, however, the joints may be covered with fabric or paper tape. Fabric tape is cemented in place with dope, paper tape with either dope or, better, with sealer or varnish.

5.785. Maintenance of Finishes. Gloss finishes of enamel or lacquer tend to lose their gloss after exposure to the weather for some time. Eventually the color apparently fades and the surface begins to chalk. The gloss and color can be restored, and any dirt deposited on the surface removed, by washing at intervals with mild soap and water. Strongly alkaline soap or cleaning agents may soften the surface of the finish enough to result in removal of an excessive amount of it with each washing; hence, they should not be used.

Camouflage finishes are inclined to become more glossy if they are rubbed either when dry or in the course of washing. They should be washed as infrequently as possible, and then with the least amount of rubbing practicable.

Refinishing, unless the old finish is removed completely, adds weight to the surface. If done frequently, the added weight may impair the performance of the craft. For that reason, refinishing should be done as seldom as is practical and then with a minimum weight of enamel or lacquer, preferably of the kind applied when the craft was made. If the old finish is badly cracked, it should be sanded down as nearly as possible to the bare wood before being refinished.

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5.8 PROPELLER MANUFACTURE

5.80. General. Propellers are usually made in special propeller plants. Their manufacture requires equipment not usually available in aircraft factories.

The making of wood propellers involves five main steps, namely: (1) selecting and preparing the laminations, (2) gluing, (3) profiling, (4) tipping, and (5) finishing.

Nominal 1-inch lumber is commonly used in the making of ordinary wood propellers. Species permitted and quality of material required are covered by the current issues of Army-Navy Aeronautical Specifications AN–L–18 and AN–P–15a and Civil Aeronautics Manual 14.

5.81. Gluing Technique. The thickness and size of propeller blocks preclude the use of glues that require the application of heat to effect their setting, except where suitable controlled humidity heating chambers or electrostatic heating equipment are available. Of the heat-setting glues, the alkaline-catalyzed, phenol-formaldehyde glues are reported to be used for this purpose. Of the cold-setting glues, the cold-setting, urea resins and caseins have sufficient water resistance for this purpose, but under the current Army–Navy specification covering propeller and test club manufacture only the cold-setting urea resins conforming to current Army–Navy specifications on these glues are permitted. The water-resistant casein glues are permitted by the Civil Aeronautics Administration.

The glues should be mixed according to the instructions of the manufacturers. For the casein glues, a 5 to 10 percent reduction in water content over that recommended for normal gluing operations aids in preventing starved joint conditions sec. 5.270).

5.810. Preparation of Lamination for Gluing. In the manufacture of propellers it is important that the laminations before gluing be uniformly dry and that all laminations be conditioned to the same moisture content. The average moisture content of the wood at the time of gluing should be between 5 and 7 percent but the maximum difference between any two laminations in any one propeller should not exceed 2 percent. These limitations are most easily met in rooms or plants where the relative humidity is controlled (sec. 5.1).

In providing laminations of the proper widths, it may be necessary to edge-glue narrow pieces. The gluing technique employed in making edge to edge joints should follow that recommended later for gluing the laminations together. The edge to edge gluing should be the first gluing operations and should be completed in time to allow a conditioning period of at least 3 days before the final surfacing of the laminations.

From the standpoint of minimizing changes in shape of the finished propeller, it is highly desirable that all laminations in any one propeller be of either flat-sawn or quarter-sawn material and of a single species. Boards that are truly flat-sawn should not be glued to boards that are truly quarter-sawn, because of their difference in shrinkage with moisture content changes. It is also desirable to arrange adjacent laminations of flat-sawn stock so the growth rings of one are reversed in position and direction to the other to further minimize stresses and distortion.

Laminations may be cut from the boards in such shapes that, when combined, they form the approximate contour of the propeller or to dimensions that are equivalent to the over-all length and width of the propeller. Making all laminations of the same width is somewhat more wasteful of material than cutting them to the approximate contour of the propeller, since a larger amount of material is taken off in the shaping operation. However, this waste is reduced somewhat by placing defects in those portions that are cut away. The full-width laminations require somewhat more attention in assembly to keep them in proper order, but uniform and adequate gluing pressure is more easily applied to them. By either method, the lumber is first surfaced lightly so as to reveal the grain and any defects which may be present. By the use of patterns the laminations are then outlined on the boards. Contoured laminations are later band-sawed. Care should be exercised that defects are eliminated and that the grain is approximately parallel to the longitudinal axis of the laminations.

Usually the laminations are then bored at a point equivalent to the center of the hub, assembled as they will later be glued in the complete propeller, and tested for approximate balance. This facilitates the final balancing of the propeller. Some shifting and interchanging of laminations is usually necessary to bring about approximate balance. Thereafter, the laminations are surfaced to final thickness.

Final surfacing of the laminations should occur immediately before gluing. The surfaces should be smooth and even and each lamination should be uniform in thickness throughout its length and width.

5.811. Gluing. The essential procedures in gluing propellers are similar to those involved in gluing straight, laminated members described in section 5.42, except that the species used are different. The propeller species are hardwoods of rather high specific gravity and require somewhat more closely controlled gluing conditions than for gluing the lighter-weight species (sec. 5.27).

5.812. Glue Spread. The glue should be spread on the surfaces by machine, which gives a more uniform coating and reduces the time otherwise spent in spreading by hand. The amount of wet glue spread, applied on one of the two contact surfaces, per 1,000 square feet of single glue line should be between 45 and 50 pounds of resin glue and between 65 and 75 pounds of casein glue. In operations where the assembly period is prolonged, it is advisable to spread both joint surfaces, in which case the above-recommended amount of glue spread per unit area of joint should be increased about 25 percent, one-half the total quantity of glue being spread on each of the contacting surfaces.

5.813. Assembly Time. The glue-coated laminations should be laid together as soon as spread. The interval between spreading the first glue and the application of pressure should not exceed 20 minutes with casein and cold-setting, urea-resin glues and it is desirable to keep the assembly time within the limits of 5 and 15 minutes. The permissible assembly periods for the low-temperature phenols vary with different glues but they are usually longer than for cold-setting, urea resins and caseins.

5.814. Temperature. Gluing with cold-setting, urea-resin glues should not be carried out when the temperature of the glue, the gluing room, or the wood is below

70° F. Temperature limitations are less critical for casein glue. Information on the curing time and temperature relations of the low-temperature phenol and high-temperature setting resin glues is given in sec. 5.263.

5.815. Pressing. For the species used in propellers, gluing pressures of 200 to 250 pounds per square inch are recommended.

Where laminations are cut to the approximate profile of the propeller, an adequate and uniform distribution of pressures during the gluing operation is somewhat complicated because the laminations in the blade section are of different widths and are echeloned from top to bottom. The difficulty is often remedied by extensive use of blocking so arranged that each lamination is filled out to approximately the same width and length. If this system is used, it is important that the blocking material be planed to the same thickness as the laminations. Variations in thickness of blocking material should not exceed 0.002 inch. Uniformity can be assured if the blocking material is prepared at the same time and with the same machine setting as the propeller laminations themselves. If the thickness of the blocking is not the same as that of the corresponding lamination, the gluing pressure will not be uniformly distributed. When the blocking is so arranged the gluing pressure can be applied in a screw press of the type illustrated in figure 5–37.

Some operators reduce the amount of blocking by the use of a great number of hand clamps. The use of hand clamps offers difficulty in securing adequate pressure. Even with the heavier type of C–clamps (table 5–13) and by crowding the work with clamps adequate pressures may not be obtained. Further, the use of many clamps retards the assembly operation and results in a delay between spreading and pressing that may prove critical, therefore, this method is not recommended.

Another method is the use of a permanent jig, constructed to receive in its proper place each lamination of a propeller of a given size. The use of such a jig facilitates the assembly of the laminations but offers other difficulties. It necessitates very exact machining of the laminations of successive propellers so that the thicknesses are constant. If the jig is made of wood it should be stored in an atmosphere where the humidity is controlled to prevent dimension changes in the jig. Coating the surfaces of the jig with wax aids in preventing adhesion of glue and avoids damage when excess glue is removed.

Applying a uniform and well-distributed pressure to laminations that are all of equal width and laid directly over each other is not difficult with pressures of the type illustrated in figure 5–37. Hand clamps are not well suited to this method. Pressure equipment sometimes used consists of several small but strongly constructed units of a screw-type press, all built to the same design and size. Any desired number of these units are then aligned on tracks, which are firmly fixed for the purpose to a good foundation, to provide a press whose length may be made to suit the length of the propeller.

5.816. Conditioning. Tests show that wood propellers change their form, blade angle, and balance when the moisture content of the assembly is changed appreciably, either by absorption or by drying out. It is desirable, in the manufacturing process, to maintain a constant average moisture content of the block during the entire procedure, including the shaping and finishing operations. This control of moisture content can only be met in adequately conditioned rooms or plants. The moisture content of the propeller assembly is increased during gluing with cold-setting glues due to the moisture supplied by the glue (sec. 5.20). When three-fourth-inch lumber is glued with cold-setting, urea-resin glues, this moisture increase is about 1 percent. With casein glues the moisture increase is about 2 percent. This moisture will diffuse through the wood and the blocks as a whole will not change moisture content if they are held in controlled humidity rooms which maintain a moisture content equilibrium for wood at 1 to 2 percent above the moisture content of the laminations at the time of gluing. Under room temperatures the conditioning should continue for at least 2 days before rough carving and from 5 to 7 additional days before finish carving, or a total conditioning period of 7 to 9 days. Moisture diffuses through cherry, mahogany, the oaks, and walnut somewhat more slowly than through birch and maple; consequently, blocks made from the first group of species should be allowed the longer conditioning period. By using a higher temperature, as 120° F., the conditioning period suggested for room temperature may be reduced by approximately one-half.

5.82. Shaping Propellers. After conditioning, the propeller blanks must be formed into finished shape by cutting and carving, partly by machine and partly by hand. Before shaping, hub faces should be made parallel with the centerline of the propeller. This insures drilling of the center bore 90 degrees to the centerline.

5.820. Rough Cutting. Square blanks require a preliminary roughing cut to bring them to approximate form before the final shaping operations can begin. Preliminary cutting of this kind is conveniently done by a wide dado head.

Roughly formed, originally square blocks and blocks formed of band-sawn laminations are rough-cut to nearly finish size by several methods.

One method employs power-driven hand planers with which the operator can cut at any angle or position he chooses. As the final form is approached, it is frequently checked against templates to guard against the removal of too much stock.

Contouring machines, duplicating the form of a master model, are excellent for final rough cutting of this kind. Machines may cut only one propeller or blade at a time, or may be arranged to handle five or six simultaneously from one master. With rigid supports and carefully mounted stock, it is possible to cut to nearly the finished shape, leaving only a small amount of hand working to bring the surfaces to final form and to balance the blades.

Heavy blocks, particularly those originally square in section, are likely to be subject to internal stresses which are released in cutting and cause some twist or warp. To allow such stresses to come to equilibrium, rough-cut blanks are stored for periods ranging from several days to a week before the finishing operations begin It is desirable to allow several days to elapse after each cut—preliminary roughing and final roughing—before the next is begun. The final roughing cut should be no closer than ⅛ inch to the finished surface.

5.821. Finish Cutting and Balancing. Leading and trailing edges are cut by rigidly mounting the block on a template which is moved against the collar of a shaper, which in turn cuts all edges in one continuous operation. This procedure requires that the blade be mounted on the template in such a way as to bring the true leading and trailing edges in contact with the shaper head. Rough edge profiling may be done before rather than after rough shaping, particularly if rough shaping is done on a contouring machine, rather than by hand-guided planer.

Final shaping and smoothing are done by hand. Tools required are planes, spoke shaves, cabinet scrapers, files, and sandpaper of varying degrees of fineness.

The finishing stage may advantageously be performed with the blade supported by a special upright mount on which the propeller can be fixed at such an angle that all surfaces are readily accessible to the finisher.

As the work proceeds, the outlines of the blade must be checked continuously by template, separate templates being required for positions on the two faces of the blade at frequent intervals along its length. The templates are cut to fit the finished contour of the blade from leading to trailing edges, which, having been cut to true profile, act as base lines from which to work. Furthermore, if the templates are provided with protractors and levels, they can quickly be placed in proper position with respect to the axis of the blade, which is mounted at a fixed angle on its support. The finisher gradually works down the material until all templates fit snugly at their proper positions. It is important that blades be carved to the maximum allowable plus tolerances, particularly with regard to width and thickness. This immediately becomes apparent when it is necessary to remove material from some portion of the propeller in order to achieve balance (sec. 5.523).

5.822. Boring Hub. One-piece propellers, continuous from tip to tip, must have their hubs bored to receive the propeller shaft fittings and the bolts which hold the fittings in place. The current Specification AN–P–15a describes acceptable methods and allowable tolerances. These cuts must be accurately centered on the hub to avoid unbalance and must be perpendicular to the axial plane of the propeller. Boring for the fittings can be accomplished by wing cutters after a pilot hole has been bored. Pilots are sometimes bored in the original laminations at the time these are marked and cut, and the laminations are assembled for gluing by driving a pin through the pilot holes. In other operations, the finished blade is placed in a jig on the boring machine which automatically centers it for boring the pilot. In either instance, once the pilot hole is bored, boring of the large hub hole is best accomplished by means of a wing cutter mounted on a spindle held at one end by the boring head and at the other by a pilot bushing in the table of the press.

Bolt holes should be bored from both sides to prevent the bits from wandering. Any of the methods discussed in section 5.66 or prescribed in the current Army-Navy Specification AN–P–15a may be employed.

5.823. Balancing. To prevent unbalance and vibration, the blades of a propeller must be equal in weight, and the weight should be distributed as equally as possible in the two blades. Each propeller must consequently be tested for balance. This is done by mounting it on a balancing arbor and allowing it to rotate while the arbor rolls on hardened steel ways, mounted in such a manner that it is free from all floor vibration. If the propeller rotates uniformly, or will stand in any position without any tendency to rock back and forth, its balance is satisfactory. If not, the heavier blade must be lightly scraped and sanded throughout its length until balance is achieved, care being taken to insure that minus thickness tolerances are not exceeded.

5.824. Checking. The final step in the woodworking operation is a complete check-over. The blade is mounted on a hub fitting and is carefully checked on an alinement jig for trueness of leading and trailing edges, as well as for profile and contour throughout its length. This jig is arranged with a series of points which follow the true outline of the leading and trailing edges and quickly reveal any excessive deviations in size or alinement. Contours are checked by templates of the type employed in the finishing operation.

5.83. Protection Against Abrasion. The tips and leading edges of propellers are subject to abrasion and must be protected. Commonly this takes the form of a cloth covering for the outer portion of the blade plus a metal strip bent over the leading edge and tip. The cloth is cut to the proper shape, stretched over the tip, and cemented in place. The metal edging is formed to lap over the tip a matter of several inches on each side and to lap the leading edge approximately 1 inch. Details of the application of the fabric sheeting and metal leading edge for protection against abrasion are given in the current issue of Army-Navy Specification AN–P–15a.

The metal should be applied over the third coat of finish, and it should be secured by brass or plated-steel, flat-head wood screws, except in the thin section near the tip, where brass or copper rivets may be used. The block should be bored for the screws and countersunk for the screwheads. The countersunk holes should be coated with a protective finish, and the metal should be dimpled into the countersunk holes to avoid damage to the wood. The rivets should be placed by essentially the same method.

5.84. Finishing Propellers. Propellers are finished primarily for protection against weathering and against rapid changes in moisture content. Finishes may also offer some resistance against mechanical wear on the surface. Finishes of high moisture-excluding effectiveness are required if the propeller is likely to be exposed to dampness for long periods; for example, during overseas shipment in the hold of a vessel. If the airplane has a camouflage finish the propeller must be given a dull, not a glossy, finish. Camouflage finishes of dark color should be as high in infrared reflectance as possible. Ordinary camouflage finishes are likely to be low in infrared reflectance, in which case they lead to development of high temperatures and low moisture contents. Black is a particularly bad color from this point of view and has been shown to lead to increased rejections of wood propellers in service in the southwestern part of the United States, the rejections coming from checking of the wood and delamination of glued joints.

For a discussion of finishes and finishing processes, particularly for moisture-excluding effectiveness of finishes, see the discussion under section 5.7.

Some authorities favor transparent finishes so that the grain of the wood is visible. However, for high moisture-excluding effectiveness, the pigmented finishes such as enamels are distinctly superior to the transparent finishes, and aluminized finishes are particularly high in effectiveness. Moreover, enamel finishes always crack when the wood beneath them develops checks or cracks. Small cracks in a smooth enamel, even in a dull camouflage enamel, are more easily detected than they are in the surface of the wood itself or in surfaces with transparent finishes.

The finish should be applied as soon as practicable after conditioning and profiling to exact shape.

Current Specification AN–P–15a requires three dip coats of sealer conforming to current Specification AN–S–17, spar varnish Specification AN–TT–V–116, or phenolic spar varnish current Specification AN–TT–V–118, with light sanding after each coat. The sealer may be reduced to not less than 18 percent nonvolatile for dipping. The metal tipping shall be applied after the third coat of sealer has dried and has been sanded. Two additional coats of sealer or varnish, as previously used for dipping, are then applied by spraying or brushing essentially at package consistency. If a camouflage finish is required, one coat of infrared reflecting enamel is specified in addition to the five coats mentioned above.

It is customary to put one or two pinhole vents in the extreme tip of the metal covering in order to throw out any water that may collect by condensation between metal and wood.

The final balancing of the propeller is accomplished by applying additional varnish or enamel to the light side of the blades.

5.85. Veneer Propellers. Wood-veneer propellers, both of the fixed pitch type and with detachable blades, are now being built of hard maple veneer. The method commonly used is to build a block out of $\frac{1}{28}$-inch thick hard maple veneer. The sheets of veneer are laid with a 30° included angle with relation to the grain of the wood, and gluing is done with a thermosetting synthetic resin glue. Propellers of this construction have been reported to show superior wear resistance and strength properties over those built with $\frac{3}{4}$-inch thick lumber laminations.

5.86. Densified Wood Propellers. Reference has been made in section 3.34 to the use of "compreg" or densified wood in propellers. In general, developments in the use of "compreg" or densified wood in propellers have followed one of three basic ideas. According to one method, the hub section is made of "compreg" or densified wood and joined by a long scarf joint to a blade of normal wood. Propellers embodying this design have been produced in quantity, and the technique of manufacture is well beyond the experimental stage. The design, of course, involves the gluing of compreg to normal wood and compreg to compreg. The gluing of compreg to itself and to normal wood is discussed under section 5.272.

In a second method, the properties of compreg and impreg are utilized to produce a propeller with a high-density, compregnated hub changing gradually to a normal-density, impregnated blade. A propeller of this design is usually made of many plies of thin veneer, with the number of plies decreasing progressively from the hub to the blade. When pressed between the platens of a hot press, the hub section, containing the greatest number of plies, is highly compressed, while the blade tip may receive no more than normal gluing pressure and the compression is negligible.

In the third method all plies are impregnated and appreciably compressed. Such propellers can be carved from (1) thick compreg blanks or (2) blanks glued up from thin compreg panels, or they can be molded from (3) precurved, uncompressed blanks of greater thickness than the final blade, or from (4) tapered plies laid up in the mold (sec. 3.32). In all four of these modifications the electrostatic heating method could be used to advantage. In modifications (1) and (4) preheating of the plies can be resorted to in place of the electrostatic heating.

5.87. Detachable Wood Propellers. A recent development, commonly called lag screw retention, has made possible the fabrication and use of detachable propellers made from natural wood as well as densified wood. This method employs the use of a multiplicity of screws installed parallel to the grain for attaching the blade in a ferrule. This type of retention avoids notches or abrupt changes in section at the highly stressed surface at the root of the blade, a condition common to most types of external retention. Furthermore, the area in shear, through which the load is transferred from the screws to the blade root, is somewhat greater than that available for similar transfer where external retention is employed. Since the screws are so located as to engage the entire cross section of the root, the tensile stress is more uniformly distributed.

CHAPTER 6. MISCELLANEOUS

6.0. LIST OF SPECIFICATIONS.

Following is a list of specifications referred to in the text of this manual, together with the sources from which they may be obtained. Specifications subsequently issued will supersede those listed in this manual.

Army-Navy Aeronautical Specifications

(Obtainable from Bureau of Aeronautics, Navy Department, Washington, D. C., or Matériel Command, Army Air Forces, Wright Field, Dayton, Ohio.)

AN-C-72	Cedar; Aircraft Port Orford.
AN-C-83	Coatings; Protective (For Wood).
AN-D-1	Dope; Cellulose-Acetate-Butyrate (Clear).
AN-D-2	Dope; Cellulose-Acetate-Butyrate (Pigmented).
AN-D-3	Dope; Cellulose-Acetate-Butyrate (Camouflage).
AN-D-8	Dope; Cellulose-Nitrate, Pigmented (Camouflage).
AN-E-3	Enamel; Aircraft, Gloss.
AN-E-7	Enamel; Camouflage, Quick-drying.
AN-F-6a	Fir; Aircraft Noble.
AN-F-7a	Fir: Aircraft Douglas.
AN-G-8	Glue; Cold-setting Resin.
AN-G-20	Glue; Application of Cold-setting Resin.
AN-H-4a	Hemlock; Aircraft Western.
AN-I-9	Insignia; National Star.
AN-L-18	Lumber; Aircraft Propeller.
AN-L-21	Lacquer; Cellulose-Nitrate, Camouflage.
AN-P-16	Pine; Aircraft Eastern White.
AN-P-17a	Poplar; Aircraft Yellow.
AN-P-18	Pine; Aircraft Western White.
AN-P-19	Pine; Aircraft Sugar.
AN-P-31	Paint; Blended Type, Coal-tar Pitch-base, Bituminous.
AN-P-43	Plywood; Aircraft, Molded (Fluid Pressure).
AN-S-6a	Spruce; Aircraft.
AN-S-17	Sealer; Liquid Wood.
AN-W-2a	Wood; Method for Kiln Drying.
AN-W-3	Wood; Determination of Moisture Content of.
AN-W-4	Wood; Determination of Specific Gravity of.
AN-NN-P-511b	Plywood and Veneer; Aircraft Flat Panel.
AN-TT-A-461	Aluminum Pigment Paste; Aircraft.
AN-TT-D-514	Dope; Cellulose-Nitrate, Clear.
AN-TT-D-551	Dope; Cellulose-Nitrate, Clear (For) Aluminum-Dope.
AN-TT-D-554	Dope; Cellulose-Nitrate, Pigmented.
AN-TT-L-51	Lacquer; Cellulose-Nitrate.
AN-TT-T-256	Thinner; Cellulose-Nitrate-Dope-and-Lacquer.
AN-TT-V-116	Varnish; Spar, Glyceryl-Phthalate.
AN-TT-V-118	Varnish; Spar, Phenol-Formaldehyde.
AN-VV-N-96	Naphtha; Petroleum Aromatic.
AN-P-15a	Propellers and Test Clubs; Fixed-Pitch Wood.

U. S. Army Specification

(Obtainable from the Matérial Command, Army Air Forces, Wright Field, Dayton, Ohio.)

3-152-A	Glue; Casein (Water-Resistant).

Army Air Forces Specifications

(Obtainable from the Matériel Command, Army Air Forces, Wright Field, Dayton, Ohio.)

14115	Surfacer; Aircraft (for wood).
98–14024	Application of Certified Casein Water-Resistant Glue.
14122	Glue; Water and Mold-Resistant Casein.

Army Ordnance Specification

(Obtainable from Chief of Ordnance, Washington, D. C.)

HOMB ES NO. 680a	General Specification, Protective Coating Materials.

Navy Department Specification

(Obtainable from the Bureau of Supplies and Accounts, Navy Department, Washington, D. C.)

52G8c	Glue; Casein, Water-Resistant.

Navy Bureau of Ships Specification

(Obtainable from the Bureau of Supplies and Accounts, Navy Department, Washington, D. C.)

52W5 (INT)	Wood Preservative; Water-Repellant, Toxic.

Federal Standard Stock Catalogue Specifications

(For sale by the Superintendent of Documents, Government Printing Office, Washington, D. C. An Alphabetical Index of Federal Specifications is available from the Superintendent of Documents at a price of 5 cents.)

CG–456	Glue; Casein Type (Water Resistant).
TT–F–336a	Filler; Wood, Paste.
TT–T–291	Thinner, paint, volatile mineral spirits.

6.1. GLOSSARY OF TERMS RELATING TO WOOD.

Air dried. (See Seasoning.)

Annual growth ring. (See Ring, annual growth.)

Bark pocket: An opening between annual growth layers that contains bark. Bark pockets appear as dark streaks on radial surfaces and as rounded areas on tangential surfaces.

Bird's-eye: A small central spot with the wood fibers arranged around it in the form of an ellipse so as to give the appearance of an eye.

Blemish: Anything, not necessarily a defect, marring the appearance of wood.

Blue stain. (See Stain, blue.)

Boards. (See Lumber.)

Bow: That distortion of a board in which the face is convex or concave longitudinally.

Boxed heart: The term used when the pith falls entirely within the four faces anywhere in the length of a piece.

Brashness: A condition of wood characterized by low resistance to shock and by abrupt failure across the grain without splintering.

Broad-leaved trees. (See Hardwoods.)

Burl: This term has the following separate and distinct meanings:

1. A large wartlike excrescence on the side of a tree. It contains a large number of buds which rarely develop. Such burls are the source of the highly-figured burl veneers and burl wood used for purely ornamental purposes.
2. A swirl or twist in the grain of the wood which usually occurs near a knot but does not contain a knot. This definition has long been used in the grading of hardwood lumber.
3. A burl in veneer is defined, for aircraft-inspection purposes, as localized severe distortion of the grain, usually rounded in outline, from one-

eighth of an inch to several inches in diameter, due to one or a cluster of small, contiguous, conical protuberances, each usually having a core, or pith, but no appreciable amount of end grain (in tangential view) surrounding it, as distinguished, on the one hand, from cross grain due to rounded protuberances with or without curly grain, or crook, and, on the other hand, from knots with distinct end grain in several to many annual rings entirely surrounding a core, or pith, all as indicated by the configuration of the annual rings on the surface of the veneer or the degree and position of cross grain.

Cant: A cant is a thick piece of lumber with or without squared edges sawed from a flitch or log and intended for remanufacture into lumber.

Cell: A general term for the minute units of wood structure. It includes fibers, vessel segments, and other elements of diverse structure and functions.

Cellulose: The carbohydrate that is the principal constituent of wood and forms the framework of the cells.

Check: A lengthwise separation of the wood, the greater part of which occurs across the rings of annual growth. Checks are usually due to nonuniform shrinkage in drying.

Close-grained wood. (See Grain.)

Coarse-grained wood. (See Grain.)

Collapse: The flattening of single cells or rows of cells in heartwood during the drying or pressure treatment of wood, characterized externally by a caved-in or corrugated appearance.

Compression failure: Deformations or buckling of the wood fibers resulting from severe stress in compression along the grain. In surface lumber they appear as fine wrinkles across the face of the piece.

Compression wood: Abnormal wood that often forms on the lower side of branches and of leaning trunks of softwood trees. Compression wood is identified by its relatively wide annual rings, usually eccentric, and its relatively large amount of summerwood, usually more than 50 percent of the width of the annual rings in which it occurs. Compression wood shrinks excessively lengthwise as compared with normal wood.

Conifer. (See Softwoods.)

Crook: That distortion of a board in which the edge is convex or concave longitudinally.

Crossband: To place the grain of layers of wood at right angles in order to minimize shrinking and swelling and consequent warping; also the layer of veneer at right angles to the face plies.

Cross break: A separation of the wood cells across the grain. Such breaks may be due to internal stresses resulting from nonuniform longitudinal shrinkage or to external forces.

Cross grain. (See Grain.)

Cup: The distortion of a board in which the face is convex or concave transversely.

Decay: Disintegration of wood substance through the action of wood-destroying fungi.

Defect: Any irregularity occurring in or on wood that may lower its strength.

Density: The mass of a body per unit volume. When expressed in the metric system, it is numerically equal to the specific gravity of the same substance.

Diagonal grain. (See Grain.)

Diamond: A distortion in drying that causes a piece of wood originally rectangular in cross section to become diamond-shaped.

Diffuse-porous woods: Hardwoods in which the pores are practically uniform in size throughout each annual ring, or decrease slightly toward the outer border of the ring.

Dimension. (See Lumber.)

Dimension stock: Squares or flat stock usually in pieces under the minimum sizes admitted in standard lumber grades, rough or dressed, green or dry, cut to the approximate dimensions required for the various products of woodworking factories.

Dote: "Dote," "doze," and "rot" are synonymous with "decay" and are any form of decay which may be evident as either a discoloration or a softening of the wood.

Dry rot: A term loosely applied to many types of decay but especially to that which, when in an advanced stage, permits the wood to be easily crushed to a dry powder. The term is actually a misnomer for any decay since all fungi require considerable moisture for growth.

Durability: A general term for permanence or lastingness. Frequently used to refer to the degree of resistance of a species or of an individual piece of wood to attack by wood-destroying fungi under conditions that favor such attack. In this connection the term "resistance to decay" is more specific.

Edge grain. (See Grain.)

Encased knot. (See Knot.)

Extractives: Substances in wood, not an integral part of the cellular structure, that can be dissolved out with hot or cold water, ether, benzene, or other relatively inert solvents.

Equilibrium moisture content: The moisture content at which wood neither gains nor loses moisture when surrounded by air at a given relative humidity and temperature.

Factory and shop lumber. (See Lumber.)

Fiber: A wood fiber is a comparatively long (one twenty-fifth or less to one-third inch), narrow, tapering cell closed at both ends.

Fiber-saturation point: The stage in the drying or in the wetting of wood at which the cell walls are saturated and the cell cavities are free from water.

Figure: The pattern produced in a wood surface by irregular coloration and by annual growth rings, rays, knots, and such deviations from regular grain as interlocked and wavy grain.

Flat grain. (See Grain.)

Flitch: A flitch is a portion of a log sawed on two or more sides and intended for remanufacture into lumber or sliced or sawed veneer. The term is also applied to the resulting sheets of veneer laid together in sequence of cutting.

Grade: The designation of the quality of a manufactured piece of wood.

Grain: The direction, size, arrangement, appearance, or quality of the fibers in wood.

- *Close-grained wood:* Wood with narrow and inconspicuous annual rings. The term is sometimes used to designate wood having small and closely spaced pores, but in this sense the term "fine textured" is more often used.
- *Coarse-grained wood:* Wood with wide and conspicuous annual rings; that is, rings in which there is considerable difference between springwood and summerwood. The term is sometimes used to designate wood with large pores, such as oak, ash, chestnut, and walnut, but in this sense the term "coarse textured" is more often used.
- *Cross grain:* Grain not parallel with the axis of a piece. It may be either diagonal or spiral grain, or a combination of the two.
- *Diagonal grain:* Annual rings at an angle with the axis of a piece as a result of sawing at an angle with the bark of the tree.
- *Edge grain:* Annual rings that form an angle of 45° or more with the wider surfaces of the piece.

Flat grain: Annual rings that form an angle of less than 45° with the wider surfaces of the piece.

Interlocked grain wood: Wood in which the fibers are inclined in one direction in a number of rings of annual growth, then gradually reverse and are inclined in an opposite direction in succeeding growth rings, then reverse again.

Open-grained wood: Common classification of painters for woods with large pores, such as oak, ash, chestnut, and walnut. Also known as "coarse textured."

Plain-sawed: Another term for flat grain.

Quarter-sawed: Another term for edge grain.

Spiral grain: A type of growth in which the fibers take a spiral course about the bole of a tree instead of the normal vertical course. The spiral may extend right-handed or left-handed around the tree trunk.

Vertical grain: Another term for edge grain.

Wavy-grained wood: Wood in which the fibers collectively take the form of waves or undulations.

Green: Unseasoned, wet.

Growth ring: (See Ring, annual growth.)

Hardwoods: The botanical group of trees that are broadleaved. The term has no reference to the actual hardness of the wood. Angiosperms is the botanical name for hardwoods.

Heart, Heartwood: The wood extending from the pith to the sapwood, the cells of which no longer participate in the life processes of the tree. Heartwood may be infiltrated with gums, resins, and other materials which usually make it darker and more decay-resistant than sapwood.

Honeycomb: Checks, often not visible at the surface, that occur in the interior of a piece, usually along the wood rays.

Interlocked-grain wood. (See Grain.)

Kiln: A heated chamber for drying lumber.

Compartment kiln: A dry kiln designed to keep the same temperature and relative humidity throughout at any given time.

Progressive kiln: A dry kiln designed to provide drying conditions that increase in severity from entrance to exit. In it the unit charge is only a part of the total charge of lumber; a unit of perhaps four truckloads is moved through the kiln in a chain of several units, from day to day, with a single unit leaving and another entering at one time.

Kiln-dried. (See Seasoning.)

Knot: That portion of a branch or limb that has become incorporated in the body of a tree.

Decayed knot: A knot which, due to advanced decay, is not so hard as the surrounding wood.

Encased knot: A knot whose rings of annual growth are not intergrown with those of the surrounding wood.

Intergrown knot: A knot whose rings of annual growth are completely intergrown with those of the surrounding wood.

Round knot: A knot whose sawn section is oval or circular.

Sound knot: A knot which is solid across its face and which is as hard as the surrounding wood.

Spike knot: A knot sawn in a lengthwise direction.

Laminated wood: An assembly built up of plies or laminations of wood that have been joined either with glue or with mechanical fastenings. Distinguished from plywood by the fact that the grain of the wood is in the same direction in all plies. As used herein, "laminated" implied the use of glue as the joining medium.

Lignin: A principal constituent of wood, second in quantity to cellulose. It incrusts the cell walls and cements the cells together.

Log: A section of the trunk of a tree in suitable length for sawing into commercial lumber.

Lumber: The product of the saw and planing mill not further manufactured than by sawing, resawing, and passing lengthwise through a standard planing machine, crosscutting to length and working. Lumber of thickness not in excess of one-quarter inch to be used for veneering is classified as veneer.

- *Use Classification.*
  - *Yard lumber:* Lumber of all sizes and patterns which is intended for general building purposes. The grading of yard lumber is based on the intended use of the particular grade and is applied to each piece with reference to its size and length when graded, without consideration to further manufacture.
  - *Factory and shop lumber:* Lumber intended to be cut up for use in further manufacture. It is graded on the basis of the percentage of the area which will produce a limited number of cuttings of a specified, or of a given minimum, size and quality.
  - *Structural lumber:* Lumber that is 2 or more inches thick and 4 or more inches wide, intended for use where working stresses are required. The grading of structural lumber is based on the strength of the piece and the use of the entire piece.
- *Size Classification.*
  - *Strips:* Yard lumber less than 2 inches thick and less than 8 inches wide.
  - *Boards:* Yard lumber less than 2 inches thick, 8 or more inches wide.
  - *Dimension:* All yard lumber except boards, strips, and timbers; that is, yard lumber from 2 inches to but not including 5 inches thick, and of any width.
  - *Timbers:* Lumber 5 or more inches in least dimension.

Mineral streak: An accumulation of mineral matter appearing as darkened areas and usually associated with an injury of some kind. Their most frequent occurrence is in the maples, hickories, yellowpoplar, and basswood.

Moisture content of wood: Weight of the water contained in the wood, expressed in percentage of the weight of the oven-dry wood.

Moisture gradient: A condition of graduated moisture content between the successive layers of a material, such as wood, due to the losing or absorbing of moisture. During seasoning the gradations are between the moisture content of the relatively dry surface layers and the wet layers at the center of the piece.

Open-grained wood. (See Grain.)

Peck: Pockets or areas of disintegrated wood caused by advanced stages of localized decay in the living tree. It is usually associated with cypress and incense cedar. There is no further development of peck once the lumber is seasoned.

Pitch pocket: An opening extending parallel to the annual rings of growth usually containing, or which has contained, pitch, either solid or liquid.

Pith: The small soft core occurring in the structural center of a log.

Pith fleck: A narrow streak resembling pith on the surface of a piece, usually brownish, up to several inches in length, resulting from the burrowing of larvae in the growing tissue of the tree.

Plywood: An assembly made of three or more layers of veneer joined with glue and usually laid with the grain of adjoining plies at right angles. Almost always an odd number of plies are used to secure balance construction.

Plain-sawed. (See Grain.)

Pocket rot: Advanced decay which appears in the form of a hole, pocket, or area of soft rot usually surrounded by apparently sound wood.

Pore. (See Vessel.)

Quarter-sawed. (See Grain.)

Radial: Coincident with a radius or radial plane from the axis of the tree or log to the circumference.

Rate of growth: The rate at which a tree has laid on wood, measured radially in the trunk or in lumber cut from the trunk. The unit of measure in use is the number of annual growth rings per inch.

Rays, wood: Strips of cells extending radially within a tree and varying in height from a few cells in some species to 4 inches or more in oak. The rays serve primarily to store food and transport it horizontally in the tree.

Ring, annual growth: The growth layer put on in a single growth year.

Ring-porous woods: A group of hardwoods in which the pores are comparatively large at the beginning of each annual ring and decrease in size more or less abruptly toward the outer portion of the ring, thus forming a distinct inner zone of pores known as the springwood and the outer zone with smaller pores known as the summerwood.

Rot. (See Decay.)

Rotary-cut veneer. (See Veneer.)

Sap: All the fluids in a tree, special secretions and excretions, such as gum, excepted.

Sapwood: The layers of wood next to the bark, usually lighter in color than the heartwood, one-half inch to 3 or more inches wide, that are actively involved in the life processes of the tree. Under most conditions sapwood is more susceptible to decay than heartwood. Sapwood is not essentially weaker or stronger than heartwood of the same species.

Sawed veneer. (See Veneer.)

Seasoning: Removing moisture from green wood in order to improve its serviceability.

Air-dried or air seasoned: Dried by exposure to the air, usually in a yard, without artificial heat.

Kiln-dried: Dried in a kiln with the use of artificial heat.

Second growth: Timber that has grown after the removal by any means of all or a large portion of the previous stand.

Shake: A separation along the grain, the greater part of which occurs between the rings of annual growth.

Shop lumber. (See Lumber.)

Sliced veneer. (See Veneer.)

Softwoods: The botanical group of trees that have needle or scalelike leaves and are evergreen for the most part, cypress, larch, and tamarack being exceptions. The term has no reference to the actual hardness of the wood. Softwoods are often referred to as conifers, and botanically they are called gymnosperms.

Specific gravity: The ratio of the weight of a body to the weight of an equal volume of water at some standard temperature.

Spiral grain. (See Grain.)

Split: A lengthwise separation of the wood, due to the tearing apart of the wood cells. It is caused by rough handling or other artificially induced stress.

Springwood: The portion of the annual growth ring that is formed during the early part of the season's growth. It is usually less dense and weaker mechanically than summerwood.

Stain, blue: A bluish or grayish discoloration of the sapwood caused by the growth of certain moldlike fungi on the surface and in the interior of the piece; made possible by the same conditions that favor the growth of other fungi.

Stain, brown: A rich brown to deep chocolate-brown discoloration of the sapwood of some pines, caused by a fungus that acts similarly to the blue-stain fungus.

Stain, sap. (See Stain, blue.)

Strength: The term in its broader sense embraces collectively all the properties of wood which enable it to resist different forces or loads. In its more restricted sense, strength may apply to any one of the mechanical properties, in which event the name of the property under consideration should be stated, thus strength in compression parallel to the grain, strength in bending, hardness, etc.

Summerwood: The portion of the annual growth ring that is formed during the latter part of the yearly growth period. It is usually more dense and stronger mechanically than springwood.

Tangential: Strictly, coincident with a tangent at the circumference of a tree or log, or parallel to such a tangent. In practice, however, it often means, roughly, coincident with a growth ring.

Texture: A term often used interchangeably with grain. (See Grain.)

Twist: A distortion caused by the turning or winding of the edges of a board so that the four corners of any face are no longer in the same plane.

Veneer: Thin sheets of wood.

Rotary-cut veneer: Veneer cut in a continuous strip by rotating a log against the edge of a knife in a lathe.

Sawed veneer: Veneer produced by sawing.

Sliced veneer: Veneer that is sliced off by moving a log, bolt, or flitch against a large knife.

Vertical grain. (See grain.)

Vessels: Wood cells of comparatively large diameter which have open ends and are set one above the other, forming continuous tubes. The openings of the vessels on the surface of a piece of wood are usually referred to as pores.

Virgin growth: The original growth of mature trees.

Wane: Bark, or lack of wood or bark, from any cause, on edge or corner of a piece.

Warp: Any variation from a true or plane surface. Warp includes bow, crook, cup, and twist, or any combination thereof.

Wavy-grained wood. (See Grain.)

Weathering: The mechanical or chemical disintegration and discoloration of the surface of wood that is caused by exposure to light, the action of dust and sand carried by winds, and the alternate shrinking and swelling of the surface fibers that come with the continual variation in moisture content brought by changes in the weather. Weathering does not include decay.

Workability: The degree of ease and smoothness of cut obtainable with hand or machine tools.

Working of wood: Change in the dimensions of a piece of wood with change in moisture content.

Yard lumber. (See Lumber.)

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